EMERGENCY STOP DEVICES

AND THE

HUMAN FACTORS OF RESPONSE

by
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ABSTRACT

Title of Thesis: Emergency Stop Devices and the Human
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The manual emergency stop was recognized as an important aspect of machine control very early during the history of powered mechanical systems. The purpose, of course, was to allow machinery to be quickly stopped during emergencies to minimize equipment damage and/or personal injury. Today, however, the emphasis of control is being shifted more and more toward totally automatic systems. Often, the importance of manual emergency stopping and override of these systems is lost in the zeal to perfect automatic controls. The problem that evolves is how and when to provide an efficient human-machine interface to allow a manual emergency stop.

Here, some common emergency stop devices are studied in light of ergonomic principles that apply during manual emergency response. Information on legal and consensus standards applicable to emergency stopping devices are included with a summary of useful recommendations regarding design and placement of devices for efficient human use.

The focus of this study is an ergonomic experiment concerning different arrangements of emergency stop pushbuttons commonly found on machinery. The results indicate that an unguarded pushbutton is superior to a guarded button in terms of the average human response time to activate and a reduction in the frequency of miss response (unsuccessful attempts at activation). Further results indicate that a large, 3 inch mushroom style pushbutton is superior to a 7/8 inch unguarded pushbutton and a significant reduction in frequency of miss response under adverse conditions is possible by redesigning the surface of the standard mushroom head.

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CHAPTER I

EMERGENCY STOPPING OF INDUSTRIAL MACHINES

The Problem

Perhaps one of the most important aspects of indus-
trial history has been the design and development of
machines. No one would deny that machinery has been the
driving force behind a 200 year revolution, a revolution
that is still in progress, and a proliferation of technol-
ogy that brought unforseen changes to labor and production.
In short, the industrial development seen in the last two
centuries has produced a standard of living that was here-
tofore impossible without use of machines. Before this
time most American families led rural lives: living,
working, and dying on the farm. Mass production did not
exist and most needed items were either made at home or
constructed by tradesmen one piece at a time.

Accidents of course have always been a familiar part
of life and work. These sudden adverse events may have
often been caused by environmental conditions or by some
form of negligence, but the results over the years have
been much the same. To a tradesman or farmer before the
industrial revolution, an accident causing loss of a limb
was likely a very rare but disastrous event. Nonetheless,
the hardship, the pain and suffering this type of accident

causes has not changed with the advent of machines; although some might say that the frequency of occurrence has greatly increased.

Safety theory that developed with industrial work has seemed to emphasize accident prevention. There can be no argument that it is better to prevent accidents than to develop responses contingent on their occurrence. For example: although it is wise to learn efficient fire fighting methods, it would be wiser indeed to strive for fire prevention; for without the fire there is truly no need for response. However, it is doubtful that human control over events could become so complete that no fire would ever occur; and one could not assume that a time will ever come when fire response will no longer be needed. Therefore, wise humans will continue to develop contingency plans. It is within this line of reasoning that situations requiring manual emergency stops of industrial machines are considered.

The Emergency Stop

It is assumed that, no matter what care is taken in design, installation, maintenance, and control of machines, situations will arise when those machines will require manual activations of an emergency stopping device. This could be due in part to one or any combination of mechanical, electrical, environmental, or human failures.

Furthermore, no machine can ever be expected to fail safely at all times. Even the most reliable electrical components will ultimately fail (if left in service indefinitely); and there is no guaranty that the failure will not cause some related dangerous condition. A machine could run wild due to a frozen relay contact, a short-circuit could place dangerous voltage on normally safe parts, or a broken ejection solenoid could cause machine parts to jam with resultant shattering of metal. These are only some of the common malfunctions that industrial operators may eventually face during their lifetimes of work. The following are some emergency conditions that could be expected to require a manual emergency stop.

    (1) An electrical explosion.

    (2) Jammed work parts.

    (3) An entangled operator stuck in the machine.

    (4) Broken machine tools.

    (5) A runaway power source.

    (6) A defect or mis-alignment of stock.

    (7) Blockage of feed.

    (8) Loosening of parts.

    (9) A sudden unbalance.

  (10) An extraneous part in the feed.

  (11) Spillage of dangerous chemicals.

  (12) An outbreak of fire.

Although this list could not by any stretch of the imagination be considered complete, the point is perfectly clear. Irrespective of automatic controls in use, emergency stopping of industrial machines has been, and will continue to be, an important part of the operator's function. Contingency plans for the execution of an emergency stop motion must be considered in operator training and machine design to ensure efficiency when an accident eventually occurs.

Types of Devices

In the early days of industrial machine design, power was often obtained from an intricate maze of overhead shafts, which transmitted rotational mechanical energy from the source or "prime mover" throughout the plant.[1] Individual machines were connected and disconnected as needed to the main shafting and obtained their power through rotating belts and pulleys. Frequently, the prime mover was a steam driven engine located in a separate room at the factory called the "powerhouse."[2] Methods of disconnecting power from individual machines consisted of crude belt shifting devices which, while push-

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[1]John Calder, The Prevention of Factory Accidents (London, New York, and Bombay, 1899), p. 136.

[2]Ibid., pp. 142-143.

ing a lever, threw the rotating belt off the main drive pulley onto a smaller loose pulley. Alternatively, some type of clutch device was often used.[3]

Attempts at electrical control during this period were primitive indeed. An electric button or bell-push alarm was often installed in various locations around the plant.[4] Assuming the batteries were charged, an alarm would ring inside the powerhouse and the attendant would shut down the prime mover when the accident alarm sounded. Obviously, the effectiveness of the system depended jointly on the response time of the attendant and the braking speed of the machine. It was likely that the flywheeling effect could keep mechanical energy applied to the system for many seconds after tripping the prime mover. Other efforts at direct control usually consisted of an electrical or mechanical device that would disconnect the head of steam from the prime mover or interrupt vacuum in condensing compound engines. These devices were activated by pushing or pulling a control device inside the plant.[5] Again, inertia of thousands of pounds of rotating shafting likely prevented instant stopping of machines.

As technology improved and individual machines became fitted with electric motors as power sources it became much easier to include an emergency stopping device.

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[3]Calder, pp. 136-140.   [4]Ibid., pp. 142-143.

[5]Ibid., p. 143.

One common arrangement was the typical dual pushbutton station still seen on many industrial machines today.[6] An example is shown in figure 1-1. The problem with many of these devices is the close proximity of start and stop buttons. In an emergency an operator could inadvertently press the wrong button causing delay in stopping a machine. Also, the stop function is not secure in the event an operator accidentally presses the start button after the emergency stop.

Other station panels have become more complex, containing multiple switches, pushbuttons, and signal lights; typically these panels are custom designed by an engineer using standard parts to assemble a control station to personal specifications.[7] A typical six unit custom built pushbutton station is shown in figure 1-2.[8] Operator confusion in an emergency is possible if the designer does not select and assemble controls in accord with established ergonomic principles.

Other types of devices have become popular for stopping industrial machines. Mushroom head pushbuttons have been in use for over fifty years with excellent results.[9] Many variations have been devised to make the

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[6]Allen Bradley Industrial Control Catalog no.107 (Milwaukee, Wisconsin, 1984), p. 160.

[7]Ibid., p. 223.   [8]Ibid.

[9]Eugene J. Verret, Manager-Corporate Product Safety Allen-Bradley Company, Personal Correspondence (Milwaukee, Wisconsin, February 5, 1985)

Dual Pushbutton
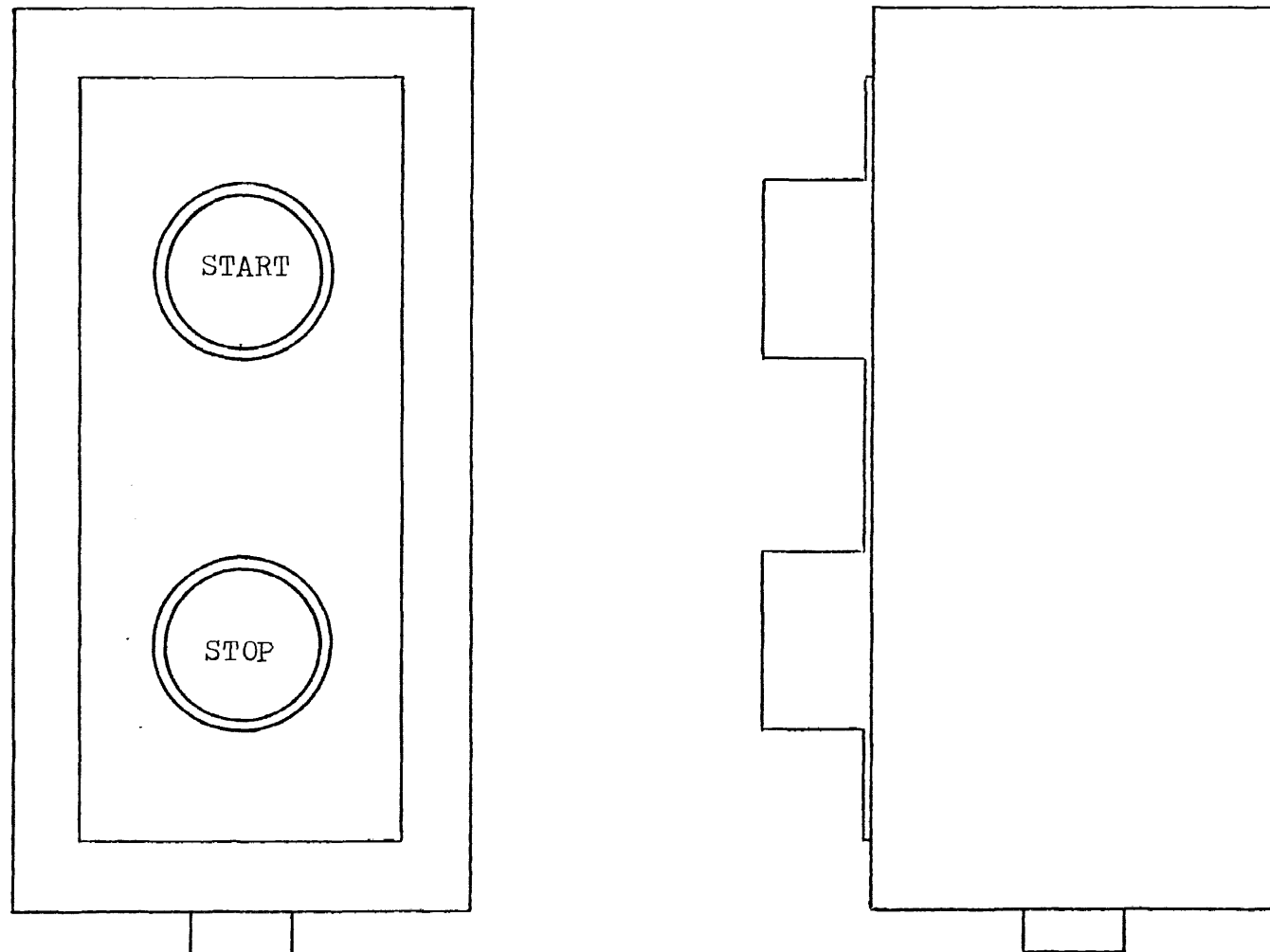
Figure 1-1

Custom Control Station
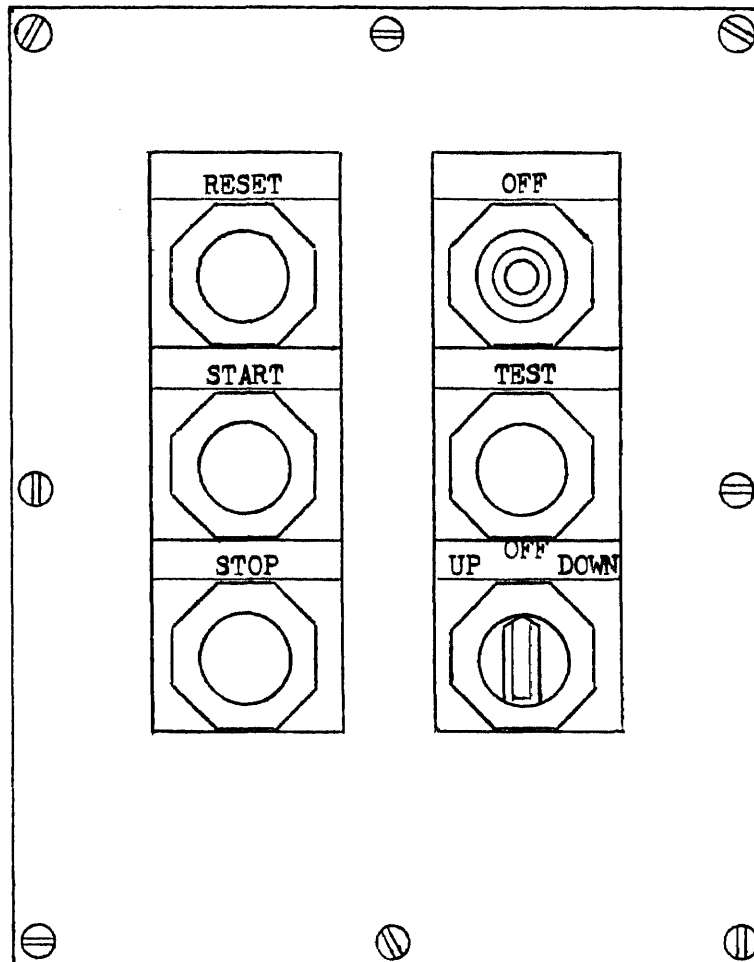
Figure 1-2

emergency stop secure. Two examples are shown in figure 1-3.[10] The first device requires a simultaneous pull and twist motion to release the mushroom head after an emergency stop and the second device requires only a pull to release. Both devices would provide a substantial margin of safety after an emergency stop if they were combined with separate start buttons; restarting the machine would require a different and distinct set of motions.

Some machines produce their own special problems when selecting a suitable emergency stopping device. Calenders, rolls, and conveyors are examples. Since the point of operation can frequently be many feet wide for rolls or many yards for conveyors, the problem of locating a stopping device becomes very difficult indeed. In some cases the solution might be to install separate pushbuttons every few feet down the length of the machine; for others, a trip-wire connected to a microswitch might be better.[11,12] This technique has also been suggested for stopping towed agricultural implements.[13] However, these

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[10]_Allen Bradley Industrial Control Catalog no.107_, p. 232.

[11]_B20.1-1947, Safety Code for Conveyors, Cableways, and Related Equipment_, American Standards Association (New York, 1947), p. 31.

[12]_Safety Code for Rubber Mills and Calenders_, Bulletin of the United States Bureau of Labor Statistics ....No 447 (New York, 1927), p. 3.

[13]J. B. Sevart and Bradley Klausmeyer, "Emergency Stop Devices for Agricultural Machinery," _Agricultural Engineering_, Volume 63, Number 9 (September, 1982), 13.

Mushroom Pushbuttons
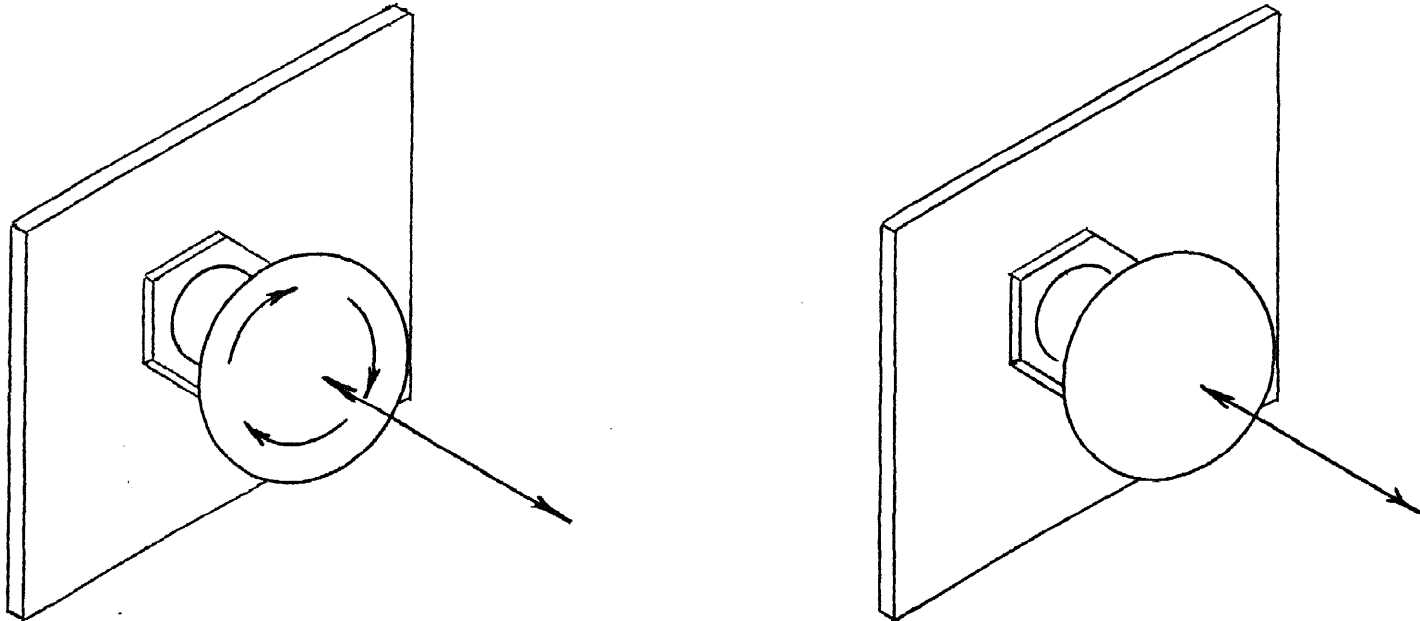
Figure 1-3

authors prefer a mechanical stop at the main driveshaft for positive control. The point of importance, when dealing with rolls, conveyors, or farm implements is clear; on this type of equipment an emergency stopping device is needed wherever a human entanglement can occur.[14] Ironically, an emergency stopping device can be useless if it cannot be reached by someone entrapped. An example of an emergency trip-wire is shown in figure 1-4.[15]

Accidents Involving Machinery

Stories of accidents involving machinery can become very gruesome accounts. In the early factory days open gears, pulleys, in-running belts, and protruding set-screws on overhead shafts often caused entanglements.[16] Many persons died or were seriously maimed when clothing got caught and bodies were whipped violently around. A person caught in a gear could have an arm almost instantly chewed to bits.[17] Very likely the equipment did not stop as inertia kept shafts turning with human bodies attached. Nevertheless, in spite of present safe-guarding techniques,

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[14]Sidney J. Williams, The Manual of Industrial Safety (Chicago and New York, 1927), p. 98.

[15]Safety Code for Rubber Mills and Calenders, pp. 3-5.

[16]Roland P. Blake, ed., Industrial Safety (Englewood Cliffs, New Jersey, 1963), pp. 12-13.

[17]Ibid.

Emergency Trip-wire

Trip-wire

Microswitch
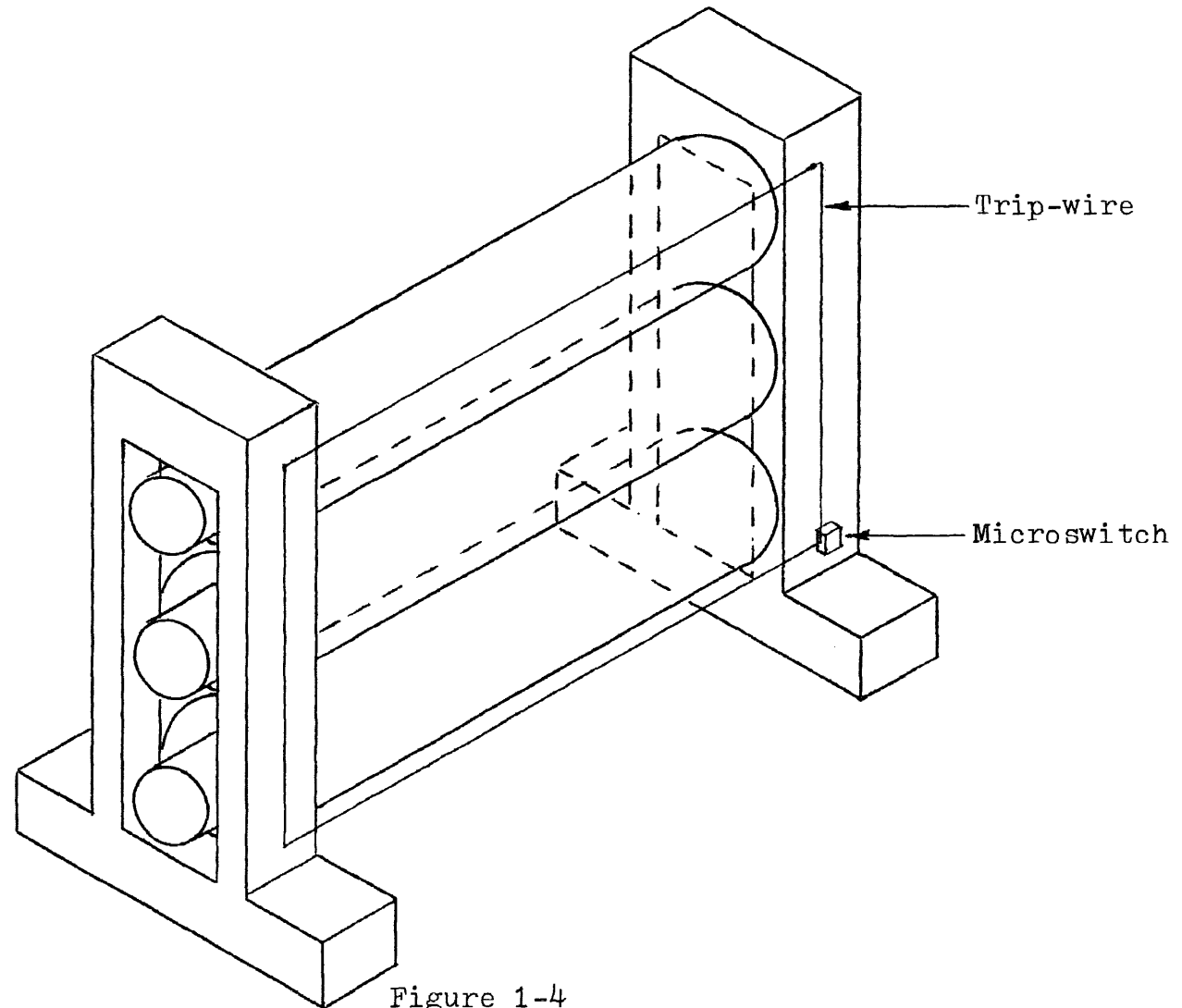
Figure 1-4

entanglements can still occur. Many machine operators know of or have heard of someone injured from this type of accident.

Factory owners seemed rarely to be interested in safety development.[18] Installing guards around dangerous machine parts cost money or could slow production and these were often seen as unnecessary expenses. Accident prevention measures very often waited for public support and legislative action, mostly being driven by newspapers printing the gory details of serious cases.[19] Sometimes these stories hit very close to home as whole communities might have been employed in one local factory. Co-workers during the shift became friends and neighbors after work and serious accidents could affect whole towns.

Today we are still affected by these sensational stories although they can now be seen directly on the local news. One recent newscast told the tale of an elderly man killed by a train in New York City.[20] While waiting at the subway station he slipped and fell to the track. Anxious bystanders tried to help him up but he had been stunned by the electricity; although he wasn't yet seriously hurt, he could not help his would be rescuers. One woman even risked personal injury and jumped down to try and push the man up; but she couldn't lift

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[18]Blake, pp. 12-13.   [19]Ibid., p. 13.

[20]Eyewitness News, WABC-TV (New York, January 1986)

him and other bystanders would not help, being afraid of electricity and the on-coming train. Several minutes later the train came into the station and crushed the man to death, even while transit personnel were handling the information that someone was on the track. Ironically, it was later found that the means to save this man's life were available at the site because, hidden at the station was a master emergency stop switch.

Although this accident points out the need for an emergency stopping device, especially where innocent by-standers can be involved in an accident, the point could be made that one was actually available and the cause of this death was ignorance of the device location. Obvi-ously, in New York City such a device would have to be hidden to prevent vandalism, however, someone at the site should have known where it was.

Other accidents can occur where no emergency stop device exists, and very often, operating characteristics of particular machines may encourage machine operators to approach a live hazard point. Maintenance or operating procedures can even require the machine to be powered and this may be so stated in the operating manual.[21] Consider the following account of an operator's injury when required to work next to a live hazard:

[21] J. B. Sevart and Bradley Klausmeyer, Emergency Stop Devices for Agricultural Machinery, American Society of Agricultural Engineers Paper No. MCR-81-401 (St. Joseph, Missouri, 1981), p. 4.

Gene Brandies, an 18 year old farmboy worked daily with a Farmhand Feedmaster model F81-C drop feeder at Carter's dairy. He knew well how it operates. Taking power from a tractor, it receives, mixes and discharges feed by means of augers which rotate at high speed in cylindrical housings. Feed is thus received, propelled into a mixing tank, mixed and forced up to a drop point where it falls through a shute into a hopper welded to a discharge sleeve several feet long. A discharge auger rotates within that hopper and sleeve.

The hopper is box-shaped, 10 inches or so wide, about 20 inches long, and open at the top to receive falling feed. Just inches below the top of the hopper, the discharge auger whirls at 380 rpm to force feed through a hole in the hopper, cut round in the circumference of the auger, and thence through the discharge sleeve to its destination at a sack or trough several feet away. The hopper is waist high to an operator standing near the clutch handle which engages the discharge auger. To one standing in that position, the auger is exposed in the hopper; it is readily visible and, in operation, openly and obviously dangerous. Gene Brandies, who grew up on a farm, had "seen enough of it," in his words, to know that it was dangerous. He knew "not to put my hand in there."

One day, however, that is what he did. He and Carl Smith were sacking cornmeal for sows in the farrow barn. Smith was in the barn filling sacks with meal which flowed from the discharge sleeve. Brandies stood outside, his back to the Feedmaster. With his right hand on the clutch handle he regulated the flow of cornmeal as the sacks were filled by Smith; with his left he steadied the shaking discharge assembly. His left hand dropped into the hopper. In a split second, the whirling blade of the auger pulled his fingers, then his hand and forearm through the pinch point at the end of the hopper and tightly into the discharge sleeve. The auger mangled Brandies' hand before Smith could run out of the barn and throw the clutch handle.[22]

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[22]Products Liability Reporter (Chicago, Illinois, 1976), pp. 14,547-14,548.

Clearly, an emergency stopping device could not have stopped Brandies' injury. Only the proper combination of operator care and machine guarding could have prevented the accident. However, it is not the intent of an emergency stopping device to prevent all injury, but to minimize the severity of injury when an accident occurs. "If one considers a reaction time of even two or three seconds, which is several times the normal instinctive reaction time of adults, and a stop time of three seconds, the power of the machine is available to do injury to the victim for only five to six seconds."[23] One can only wonder how much more than six seconds elapsed between Brandies' entanglement and Smith's emergency stop of the Feedmaster.

Safety engineers and accident investigators have long acknowledged the value of the emergency stop, especially during those accidents where injury becomes time dependent.[24] The following excerpt illustrates the situation:

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[23]Sevart and Klausmeyer, 1981, p. 7.

[24]Ibid., pp. 2-3.

...I have investigated many accidents where
farmers or industrial workers were caught in
in-running nip points and experienced severe
damage to the nerve and circulatory systems of
the arm (s) without having broken a bone. The
medical profession can repair broken bones but
the gross burning and erosion of the nerve and
circulatory systems are non-repairable and re-
sult in amputation. I have also encountered
accidents where farmers got one or more addi-
tional limbs entangled in the machinery while
trying to get the first trapped limb out. The
emergency stop device is most useful to reduce
the injury severity in such accidents. Shock
is also minimized if the machine can be quickly
shut down.[25]

Trappers have noted that animals caught in traps
will do almost anything to free themselves; even if this
means knawing or wrenching a trapped limb completely off.
Humans have shown a similar instinct when caught in a
machine by attempting to wrench a trapped limb free using
another hand or foot. Frequently, as the above author
points out, the result of this action is further entangle-
ment and more serious injury. Again, an emergency stop-
ping device cannot prevent this type of accident from
first occurring. However, it can provide a reliable means
for an entrapped operator to quickly stop the machine
before instinctive wrenching can cause further entangle-
ment. The following account of an accident with a print-
ing press illustrates the problem:

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[25]J. B. Sevart, P.E., Personal Correspondence
(Wichita, Kansas, 1984).

After each run, the press was stopped, pans were placed under the rollers, and the press was turned on so that all six units were idling. Each crew member, armed with a bottle filled with naptha, a cleaning solvent, then stood on a catwalk running around each unit, and into the machine and squirted naptha on the unguarded, revolving rollers. Some of the naptha, mixed with ink, would be thrown back onto the catwalk as the rollers turned. Most of the ink and solvent would drip onto the lowest rollers and into the pans. The lower roller was cleaned by a blade that scraped off the accumulating residue. This blade was adjusted before and during the process to ensure that all the residue was removed. Wansor's injuries occurred while he was making this adjustment...

To adjust the scraper blade, Wansor had to crouch on the catwalk to avoid being hit by the rollers above him, turn two screws located about fifty inches apart, then back out in the same Russian-folk-dance crouched walk. On the date involved here, Wansor had finished adjusting the screws and was beginning to back out of the machine when...his right hand became caught in the unguarded rollers. He attempted to pull his hand out but succeeded only in entangling his left hand as well and in the struggle caught his hair on the upper rollers. Although the machine was quickly turned off, Wansor's hands were severely mangled. Despite extensive medical treatment, he lost most of the fingers and part of the thumb from his right hand and two fingers from his left hand.[26]

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[26]Products Liability Reporter (Chicago, Illinois, 1979), p. 18,083.

Although it is apparent that an emergency stopping device located near these rolls would not have prevented the initial injury to Wansor's right hand, it is possible that further injuries, including those to the left hand could have been avoided. Clearly, within a split second of entanglement, fear and an instant recognition of hopelessness caused Wansor to react in panic; and, in the attempt to wrench the trapped hand free further unnecessary damage occurred. The questions might be asked: why did the machine designer require operators to enter such a dangerous area, especially in such an unnatural human posture (crouching)? Why were better procedures for cleaning not considered in the design? The answers to these, and other related questions can only be explained in terms of foresight. Obviously, the designer of this machine did not envision the mangling of hands; therefore, cleaning procedures may have been overlooked in the zeal to perfect an efficient mechanical design.

Another area that can be overlooked by machine designers is the frequent need to manually clear a stalled machine. Industrial operators can be faced with the following situation:

> Perhaps the most dangerous of all operating modes is that where the hazardous rolls, or other moving parts, are stalled due to a plug. It is simply contrary to normal human behavior to turn a stopped machine off. (Who hasn't replaced a light bulb to find with surprise that the light was still on.) Under this condition, the opera-

tor begins to remove the plug and does not
recognize any danger because the machine is
"stopped". As the plug is diminished, sud-
denly the torque of the drive is sufficient
to drive the machine and a slip clutch re-
engages. The condition just described is a
trap and represents a very dangerous con-
dition that the ordinary operator does not
comprehend under the mental pressures of
having a specific, but unrelated task to
perform,...27

The preceeding accounts have all focused on the human

aspects of accidental contact with machines and the need

for an emergency stopping device located close to the

point of hazard, to minimize severity of injury. Largely,

the damage caused to machines in accidents where they

cannot be quickly stopped has been ignored. Perhaps

these stories are not nearly as spectacular as those

causing serious human injury and are, therefore, quickly

forgotten. In any case, the emergency stopping device,

when properly placed can minimize the severity of damage

and monetary loss in an accident. The following two

cases are examples (author's personal observations):

Case 1

In the pharmaceutical industry, tablets are formed

on a rotary mechanical press which takes powder and presses

it between two punches (rams) in a die. Upper and lower

punches operate vertically and, as a die table revolves,

27Sevart and Klausmeyer, 1981, p. 4.

motion of many sets of punches are controlled by station-
ary cams. The sequence of tablet formation is as follows;
powder enters a force feeder mechanism positioned 0.003
inch above the revolving die table; upper punches ride
the cam track and clear this feeder assembly while lower
punches are drawn down in the dies to pull powder into
the chambers; upper punches are then lowered into the
die holes and pressure up to five tons is provided to
press the tablets; upper punches are then withdrawn and,
as the die table completes its revolution, lower punches
are raised in their dies to eject the completed tablets.
This sequence continues indefinitely.

One day during a press run an operator inadvertently
forgot to tighten a die retaining screw and ultimately
this die was forced out of its mount. The die table was
revolving at about thirty rpm when die contact was made
with the feeder. On the first revolution (2 seconds) the
feeder was torn from its mount. On succeeding revolutions,
pieces of broken feeder were mangled further and ultimately
bits of metal became jammed in other dies, thereby stall-
ing the machine. It was estimated that the accident dur-
ation was on the order of ten seconds.

During the accident the operator did not stop the
machine because the stop button was located under the
feeder assembly. No emergency stopping device was in-
cluded any place else on the machine. Cost of the acci-
dent was over $20,000 due to broken machine parts and

complete destruction of one set of punches and dies.

Case 2

Pharmaceutical capsules are often made on similar types of rotating machines. However, revolving die tables usually index and remain at one stationary position for a certain length of time. Operations performed during dwell time include: empty capsule placement, opening, filling, closing, and cleaning, all of which are done at different station locations.

One day during a capsule run vibrations loosened a retaining screw holding the powder hopper in place. Suddenly the dosing mechanism contacted the powder hopper and breaking of metal ensued.

On the side of the machine, away from all moving parts, was a large, red, mushroom style, emergency stop pushbutton which the operator quickly activated. At the time of the accident it was estimated that the dosing mechanism was rotating at thirty-five rpm. On the first revolution (1.7 seconds) the dosing mechanism and powder hopper were severely damaged but the emergency stop was completed before any further revolutions were made. Cost of the accident was estimated at about $2,500 to replace the broken parts.

These two accidents are typical of what can happen with high speed rotary machines when machine parts loosen, work parts jam, or extraneous debris finds its way into

areas of tight clearance. Although these two particular accidents cannot be directly compared due to differences in machine operation, the fact that the indexing style capsule machine was stopped before it jammed completely is a significant observation. Clearly, the operator in case 1 did not attempt an emergency stop because the machine controls were too close to the danger zone. In fact, this particular operator backed away from the machine in order to avoid flying bits of metal. Furthermore, there was no master emergency stopping device in the room. Machines that jam under these conditions are sure to be severely damaged, therefore, provisions must be made for the emergency stop. In case 2 the means for stopping the machine quickly were included in the original design. Obviously, the designer considered operator and machine safety as an important criterion.

CHAPTER II

STANDARDS AND REGULATIONS: EMERGENCY STOPPING OF MACHINES

Background of Development

"Industrial accidents cost this country 35,000 human lives and more than $500,000,000 annually. In addition, dismemberments and other serious injuries total about 350,000 yearly while the number of minor accidents, causing loss of time, exceeds 2,000,000."[28] These statements seem impressive today but even more so when one considers that they were written in the early 1900's.

The situation that this author was referring to (industrial accidents) probably included many different types of accidents such as fires, explosions, and collisions as well as machinery related accidents which are of interest here. But it cannot be denied that machinery mishaps have been a significant factor in industrial safety standards development and legislative action throughout the history of industrialization. For example: the first law requiring guarding of dangerous machine parts was enacted in Massachusetts in 1877.[29] During this time period

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[28]George Alvin Cowee, _Practical Safety Methods and Devices_ (New York, 1916), p. iii.

[29]Blake, p. 13.

many young girls (children) were employed in textile mills to operate spinning machines. They were required to work with their hands very close to unguarded gears and a very common accident was mangling of fingers. Strong public opinion finally resulted in passage of legislation only after many years had passed and an untold number of mangled young hands had accrued.[30]

This sequence seems to have been repeated time after time throughout history. In fact, it was once stated by a railroad executive when the Railway Safety Act was being considered (1893) that the cost of burying a man killed in an accident was less than the cost of putting air brakes on a car.[31] This man, as pointed out by Hammer, was probably not inherently evil; rather, the statement indicated that the major industrial concern was often economics rather than safety. Therefore, it often remained for public indignation and concern to force law makers to take required action while industry dragged its feet.[32]

In the 1900's, realizing that something would ultimately be done and fearing a growing intrusion of governmental regulations, industries began to take action by forming committees and organizations to propose voluntary

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[30]Blake, p. 13.

[31]Willie Hammer, Occupational Safety Management and Engineering (Englewood Cliffs, New Jersey, 1981), p. 1.

[32]Blake, pp. 13-14.

safety standards.[33] In 1911, at the request of the
Association of Iron and Steel Electrical Engineers a na-
tional industrial safety conference was called.[34] This
resulted in the formation of the National Council for
Industrial Safety (1913) which later became known as the
National Safety Council. Their basic premise was: that
the same principles that were being used to expand pro-
duction could also be used to prevent accidents through
a proper application of Engineering, Education, and En-
forcement - the "Three E's of Safety."[35]

One of the early results of the National Safety
Council's efforts was the sponsoring of the American
Engineering Standards Committee which developed voluntary
consensus standards. This committee, which became the
American Standards Association, then the United States of
America Standards Institute, and finally (1969) the
American National Standards Institute (ANSI) developed
safety codes applicable to various industrial operations.[36]
Some examples of early safety codes are: the Safety Code
for Power Presses and Foot and Hand Presses (1922), the
Safety Code for Woodworking Plants (1924), and the Safety

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[33]Hammer, p. 67.

[34]Frank McElroy, ed., Accident Prevention Manual for
Industrial Operations (Chicago, Illinois, 1974), pp. 5-6.

[35]Ibid., p. 6.

[36]American National Standard Safety Requirements for
the Construction, Care, and Use of Mechanical Power Presses,
ANSI B11.1-1971 (New York, 1971), p. 3.

<u>Code for Mechanical Power Transmission Apparatus</u> (1927).

ANSI standards developed over the years have never been mandatory. Each current standard contains the phrase:

>   An American National Standard implies a consensus
> of those substantially concerned with its scope and
> provisions. An American National Standard is intend-
> ed as a guide to aid the manufacturer, the consumer,
> and the general public. The existence of an American
> National Standard does not in any respect preclude
> anyone, whether he has approved the standard or not,
> from manufacturing, marketing, purchasing, or using
> products, processes, or procedures not conforming to
> the standard.[37]

This means that neither manufacturers nor consumers are required by law to manufacture or use products in accordance with any consensus standard. However, it often behooves them to do so because, if a victim can show that use of a non-conforming product resulted in an accident, the probability of him/her presenting a successful lawsuit greatly increases.[38] Furthermore, use of a product conforming to an ANSI standard does not necessarily mean that product is completely safe and an accident cannot occur. Although some may believe that products conforming to consensus standards, such as ANSI standards, are safe to use, this may not always be true. It must be remembered

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[37]<u>American National Standard for Machine Tools-Mechanical Power Presses-Safety Requirements for Construction, Care, and Use</u>, ANSI B11.1-1982, (New York, 1982), p. 2.

[38]Hammer, p. 73.

that a consensus standard implies an agreement among
"...those substantially concerned with its scope and
provisions."[39] and may include significant input from
committee members representing manufacturers. As such, a
consensus standard could be interpreted as the minimum
safety requirements the industry was willing to accept.[40]
Therefore, the motto, "let the buyer/user beware" should
still be applied.

ANSI Standards Applicable to Emergency Stopping Devices

Many consensus standards developed over the years and
applicable to industrial machines have called for or re-
ferred to an emergency stopping device. Unfortunately,
most of these standards do not provide specific informa-
tion on how the emergency stop is to be accomplished,
where the device should be located, or what type of device
should be used. The following excerpt from a personal
correspondence with Mr. Carvin DiGiovanni - Assistant
Secretary, B11 American National Standards Committee
illustrates the situation:

> ...regarding your research on emergency stop
> devices, I can advise you that existing standards
> language relevant to this subject that are listed
> throughout the 19 B11 standards are done so in
> performance styled language. This means that each
> standard calls for the need of an emergency stop

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[39]ANSI B11.1-1982, p. 2.   [40]Hammer, p. 67.

device, then describes what it is supposed to do, and then may briefly describe its location in terms of accessibility to the operator. The standard's reference however, does not provide specific standards language on how this is to be accomplished. Thus, leaving the requirements to remain flexible for each manufacturer to design a system innovated for each piece of equipment.[41]

The 19 B11 standards referred to above are:

B11.1 - Mechanical Power Presses

B11.2 - Hydraulic Power Presses

B11.3 - Power Press Brakes

B11.4 - Shears

B11.5 - Iron Workers

B11.6 - Lathes

B11.7 - Cold Headers and Cold Formers

B11.8 - Drilling, Milling, and Boring Machines

B11.9 - Grinding Machines

B11.10 - Metal Sawing Machines

B11.11 - Gear Cutting Machines

B11.12 - Roll Forming and Roll Bending Machines

B11.13 - Single and Multiple Spindle Automatic Screw/Bar and Chucking Machines

B11.14 - Coil Slitting Machines/Systems

B11.15 - Pipe, Tube, and/or Shape Bending Machines

B11.16 - (To be assigned)

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[41]Mr. Carvin DiGiovanni, Personal Correspondence (McLean, Virginia, October 29, 1984)

B11.17 - Horizontal Hydraulic Extrusion Presses

B11.18 - Coil Processing Equipment

B11.19 - Guards and Devices

Although, as Mr DiGiovanni points out, performance styled language can allow flexibility for manufacturers to design emergency stopping devices according to their own particular needs, consistency among functionally similar pieces of equipment has been ignored. Consider the operator who changes jobs or, perhaps, operates several different brands of machine within the same shop. On one machine the emergency stopping device could be located on the right side of a point of operation hazard while on another machine made by a different manufacturer, it could be on the left. Furthermore, different devices could be used. This question of consistency is currently being considered, among other problems, by the American Foundrymen's Society Safety Committee. Consider the following excerpt from a personal correspondence with Mr. William B. Huelsen - Vice President, Environmental Affairs, American Foundymen's Society:

> The American Foundrymen's Society Safety Committee is working on a series of graphic machine symbols which are intended to replace printed legend plates on push buttons and selector switch controls. This committee has not only been working on the graphic symbols, but also the ergonomics...
> One of the problems our committee has wrestled with on many occasions is the location of

the master emergency stop on each control panel...

At one time our committee thought perhaps the emergency stop button should be located in the center of each control panel, but one of our members had experience with this on one of his machines and found that the operator occasionally brushed by the emergency stop button and shut the equipment down. The machine then had to be manually returned to its initial mode of operation and restarted. We have concluded though that the master stop button should be located at the same place on each control panel, even though it may be out of reach of the operator in an emergency. Additional stop switches would be connected in series with the master stop and might be actuated by presence sensing devices such as photo electric cells, light shields, pressure pads, cables, etc. specifically designed and located so they could be easily actuated in an emergency by the operator(s).[42]

Obviously, the question of where the master emergency stopping device should be located has not yet been completely resolved. Security against inadvertent stopping of machines (Bumping) often poses a significant concern.

ANSI B11.1-1982, the <u>American National Standard for Machine Tools-Mechanical Power Presses-Safety Requirements for Construction, Care, and Use</u> contains the following requirements pertaining to emergency stopping devices:

2. Definitions

2.49 <u>Stop Control</u>. An operator control designed to immediately deactivate the clutch control and activate the brake to stop slide motion.

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[42]William B. Huelsen, Personal Correspondence (Des Plaines, Illinois, December 5, 1984)

3. Construction, Reconstruction, and Modification

3.3 Brakes. Friction brakes provided for stopping
or holding the slide movement shall be set with com-
pression springs. Brake capacity shall be sufficient
to stop the motion of the slide quickly and shall be
capable of holding the slide and its attachments at
any point in its travel.

3.5.2 Controls

3.5.2.1 Stop Control. A red color stop control shall
be provided with the clutch/brake control systems.
Momentary operation of the stop control shall immedi-
ately deactivate the clutch and apply the brake. The
stop control shall override any other control, and
reactuation of the clutch shall require use of the
operating (tripping) means which has been selected.

E3.5.2* Controls

E3.5.2.1 Stop Control. A stop control should be
available to each operator....

3.6 Electrical

3.6.2 Motor-Start Button. The motor start button
shall be protected against accidental operation.[43]

Currently the ANSI B11.19 subcommittee is working

on a standard that will establish the requirements for

guards, devices, and methods to be used when they are

called for in the other ANSI B11 series of standards.

The following excerpts from ANSI B11.19 Draft - 2/15/85,

the American National Standard Performance Criteria for

the Construction, Care, and Operation of Safeguards as

Specified in the Other B11 Standards, apply to emergency

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*In current ANSI standards an (E) designation refers
to explanatory material which is not part of the standard.

[43]ANSI B11.1-1982, pp. 14, 23-24, 26, 30.

stopping devices:

2. Definitions

2.40 <u>Operator Controls</u>.
An operator control is a pushbutton, switch, lever,
hand wheel or other device activated by the operator
which initiates, cycles, controls or stops the mo-
tion of a machine tool.

5. Auxiliary Devices

5.2 <u>Stop Control</u>

The requirements of this section shall apply to all
stop controls recommended for safeguarding the haz-
ards associated with the point of operation of ma-
chine tools by the other B11 safety standards or by
section 4 of this standard.

5.2.1 The stop control shall be designed and con-
structed as a means of stopping hazardous motion by:

A. Immediately deactivating and overriding all
other controls or;

B. Disconnecting the machine tool from the power
or drive source or;

C. Deactivating or overriding the controls or dis-
connecting the power source and simultaneously
applying a brake to stop motion or;

D. Deactivating or overriding the controls or dis-
connecting the power source and simultaneously re-
versing the hazardous motion.

5.2.2 An emergency stop control shall be provided
for each operator control station or position and
shall be readily distinguishable and shall be
clearly labeled.

E5.2 An emergency stop control is sometimes referred
to as a master control or stop control.

E5.2.1 The stopping of hazardous motion is necessary
for a stop control to provide safeguarding of the
operator.

If the driven portion of the machine tool coasts
after the stop control is activated, it may be

necessary to use a brake in conjunction with the
stop control to achieve the desired stopping per-
formance.

E5.2.2 A typical stop control may be a button, cable,
foot control, trip bar or other sensing means.

5.5 Control Reliability

E5.5.1 ...Where possible, all controls and pilot
lights utilized on a machine tool should be stan-
dardized in configuration, location, function and
color code. The controls and indicators should be
accessable and readily visible from the operator's
station or normal location....

5.7 Die and Machine Malfunction Detection and
Monitoring Devices

5.7.1 ...Restarting of the machine tool after a
malfunction is detected shall require start up of
the machine tool system at the operator's station.[44]

As can be seen from the representative excerpts pre-

sented from ANSI B11.1 and the B11.19 draft, emergency

stop control requirements are written in performance

styled language. The need for the device in order to

safeguard the operator and the machine from accident

injury and damage has been established and this is re-

flected in these ANSI consensus standards. But, within

very general limits, the location and the design of the

device is left to the discretion of individual manufac-

turers who may choose to utilize available technology in

order to design the most efficient system practical, or

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[44]American National Standard Performance Criteria for
the Construction, Care and Operation of Safeguards as Spec-
ified in the Other B11 Machine Tool Safety Standards, ANSI
B11.19 Draft 2/15/85 (New York, 1985), pp. 4, 9, 39, 41-43.

may ignore established ergonomic principles and opt for a less efficient system.

Consensus standards over the years have shown many changes that accrued due to industrial development. Obviously, recommendations applied to early industrial practices would have to change with advancing technology as the inherent hazards of these processes changed. For example: consensus standards applicable to early shops using overhead shafting for mechanical power transmission would likely not be applied today in modern manufacturing plants. The hazards of this type of apparatus have largely been superceded by newer hazards inherent with modern machines.

As consensus standards were developing, occasionally some particular recommendation would conflict with established ergonomic principles; principles that were known long before the standard was written. Sometimes these standards went against recommendations made by other authorities or even against other standards promulgated by the same organization at the same time period. When these standards are read today the reader might wonder what circumstances at the time caused the error to be made, especially when the error is blatantly obvious.

The following excerpts follow the historical development of ANSI B15.1-1984, the Safety Standard for Mechanical Power Transmission Apparatus as it is known today. They provide examples of changing recommendations and standards in conflict with established ergonomic principles.

B15-1927

Part III Starting and Stopping Devices

Section 31 Belt Shifters, Clutches, Shippers,
        Poles, Perches, and Fasteners

Rule 310 - Belt Shifters

    (c)   All belt and clutch shifters of the
           same type in each shop should move in
           the same direction to stop machines,
           i.e., either all right or all left.[45]

Part VI Discussion

3. Power Control - Among the methods used for power
control may be mentioned motor switches, friction
clutches, belt shifters and engine stops. The means
for controlling power should be positive and should
be so arranged as to permit of operation from a point
not more than 100 feet from any machine driven from
the source of power in question. If the stations can
be arranged to be within 50 feet of any machine, it
is highly advisable. There will be cases, as for
example in the steel industry, where a greater dis-
tance from the machine becomes necessary.
    It is advisable to mark the stop station with
a mark easily distinguishable - green bands on posts
and green circles on walls are recommended, together
with a sign "Stop Station" or "Emergency Stop." A
light of characteristic color should be added in
shops where night work is carried on.
    All electrical safety devices should operate
by the opening of a normally closed circuit. Any
failure of the current or device will thus be in-
dicated by the stopping of the prime mover. It
is advisable to test such devices daily by shut-
ting off the power at noon or night by such means.[46]

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[45]American Standard Safety Code for Mechanical Power
Transmission Apparatus, B15-1927 (New York, 1927), p. 17.

[46]Ibid., p. 25.

<u>B15.1-1953</u>

Entries applicable to starting and stopping devices
are the same as in B15-1927.

<u>B15.1-1972</u>

This edition of the B15.1 standard does not contain
any reference applicable to emergency stopping devices.
The appendix, which was not part of the standard, contains
the following reference:

> A6.6.3 All belt and clutch shifters of the same
> type in each shop should move in the same direc-
> tion to stop machines, i.e., either all right or
> all left.[47]

<u>B15.1-1984</u>

> 3 SAFEGUARDING OF HAZARDS
>
> 3.2 Types of Safeguards
>
> 3.2.2 <u>Devices</u>
> (a) A motion hazard safeguarding device shall pro-
> vide protection to personnel by:
>
> (1) preventing and/or stopping normal motion of the
> mechanical power transmission source of hazard if
> personnel inadvertently enter the hazardous area;

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[47]<u>Safety Standard for Mechanical Power Transmission
Apparatus</u>, ANSI B15.1-1972 (New York, 1972), p. 9.

(2) providing the means to stop the system in the event of inadvertent involvement with the hazard.

E3.2.2 Devices

(2) Emergency pull cords, body bars, and/or other means to stop the system are examples of this type of device.[48]

Clearly, the early editions of B15.1 were heavily influenced by the state-of-the-art in power transmission at the time with references to belt shifters and clutches as examples. These indicate the extensive use of shafting, pulleys, and belts for power transmission throughout industry. However, it should be noted that early editions (1927 and 1953) included material relevant to emergency stopping of the equipment while in 1972 these references were dropped. They were not revived again until 1984. One could not assume that between 1972 and 1984 emergency stopping of power transmission apparatus was no longer needed; rather, it might be surmised that committee members at that time did not see or could not agree on the need for emergency stopping devices. It must be remembered that consensus standards cannot be regarded as indications of maximum concern for safety, but often they reflect minimum acceptable standards. [49]

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[48]Safety Standard for Mechanical Power Transmission Apparatus, ANSI B15.1-1984 (New York, 1984), pp. 7-10.

[49]Hammer, p. 67.

Furthermore, these standards can contain serious errors of judgement that are very difficult to explain. Until 1972 the B15.1 standard advocated use of green bands on posts and green circles on walls to designate emergency stop control locations, even though this is clearly in violation of long established precedence denoting red as the emergency color. "Red has been the universal danger color for many years."[50] This statement was made in 1916. Also, the <u>American Standard Safety Color Code for Marking Physical Hazards and the Identification of Certain Equipment</u>, Z53.1-1945 stated:

2. Color Identification

2.1 <u>Red</u>. Red shall be the basic color for the identification of:
    (a) Fire Protection Equipment and Apparatus
    (b) Danger

    (c) Stop[51]

Clearly, any standard retained in the 1953 edition and recommending the color green be used to designate emergency stop control locations is in violation of Z53.1. One can only wonder if any serious accidents occurred due to use of this recommendation.

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[50]Cowee, p. 30.

[51]<u>American Standard Safety Color Code for Marking Physical Hazards and the Identification of Certain Equipment</u>, Z53.1-1945 (New York, 1945), p. 5.

Certain industries such as paper and pulp mills and rubber mills utilized equipment that quickly developed a reputation for potentially severe, possibly fatal human entanglements.[52] The machines that were used in paper and rubber processing often contained sets of revolving rollers (rolls) or calenders which produced in-running nip points. Depending on the spacing between rolls, hair, fingers, hands, arms, and even legs could become entangled with disastrous consequences. During rubber processing these rolls were often heated internally and human entanglements could produce additional heat through friction with resultant tearing and burning of flesh.[53] Catching significant amounts of hair between rolls could easily result in scalping. The possibility of bleeding to death from any of these accidents existed if the means were not available to stop the machine quickly and someone was not available to perform first aid.

Early ANSI standards covering this equipment reflected the need for emergency stopping devices. Also, the severity of potential accidents resulted in these standards specifying design and location of devices to be used. Consider the following excerpts regarding emergency stop devices taken from the American Standard Safety Code

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[52]Williams, p. 98.

[53]American Standard Safety Code for Mills and Calenders In the Rubber Industry, B28.1-1949 (New York, 1949), p. 5.

for Paper and Pulp Mills (P1-1925) and the Safety Code for Rubber Mills and Calenders (B28-1927):

P1-1925

PART VII - MACHINE ROOM

Rule 701. Emergency stops.

Both the operating and the back sides of the paper machines shall be equipped with devices that will stop the machine quickly in an emergency. The device shall consist of push buttons for electric motive power or electrically operated engine stops, pull cords connected direct to the prime mover, control clutches, etc. The devices shall be tested frequently by making use of them when stopping the machine.

PART VIII - FINISHING ROOM

Section 80. SUPERCALENDERS

Rule 803. Emergency stops.

Push buttons (for electric power) or manually operated quick power-disconnecting devices shall be provided on all sides of the machine within easy reach of all employees.[54]

B28-1927

SAFETY-TRIP CONTROLS AND QUICK-STOP FACILITIES

Rule 110. Safety-trip controls -- Mills.

(a) A safety trip rod or tight-wire cable for each individual mill shall be provided front and back of

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[54]Safety Code For Paper and Pulp Mills, P1-1925 (New York, 1925), pp. 22, 26.

all mills, extending the length of the face of the
rolls. It shall operate sensitively if it is pushed
or if it is pulled.

(b) The normal location of the safety-trip rod over
the front roll shall be two (2) inches to four (4)
inches in from the edge of the front roll and not
more than sixty-nine (69) inches above the working
floor level on which the operator stands, with pro-
vision made for adjustment of three (3) inches either
up or down.

(c) The normal location of the safety-trip rod
at the back of the mill shall be two (2) inches
to four (4) inches in from the edge of the back
roll and shall be in the same horizontal plane
as the safety-trip bar over the front roll, and
the length of the lever from fulcrum shall be the
same.

Rule 112

The locations of safety-trips apply to all sizes
of mills.

Rule 120. Safety-trip control -- Calenders.

(a) A safety-trip rod or a tight-wire cable shall
be provided across the front and the back of all
calenders, extending the length of face of rolls,
to operate sensitively if it is pushed or if it is
pulled. This rod shall be at a height not more
than sixty-nine (69) inches above the working floor
level or platform on which the operator stands and
shall be within easy reach, with provision made for
adjustment either up or down of three (3) inches in
each direction.

(b) On each side of all calenders and near both ends
of the face of the roll there shall be a vertical
tight-wire cable connecting with the bar tipping
mechanism at the top and fastened to the frame with-
in twelve (12) inches of the floor. These cables
should be positioned at a distance of not more than
twelve (12) inches from the face of the roll and at
a distance of not less than one (1) inch from calen-
der frame.

OPERATING RULES

Rule 150

Safety stops on mills and calenders should be tested

daily, and accurate measurements of distance of travel shall be taken at least once every thirty (30) days.[55]

Obviously, the severity of accidents which routinely occurred with rolls and calenders prompted committee members to include significant emphasis on emergency stopping within these early standards. Consider the following statement: "It is realized that the quick stopping of mills and calenders is a very important factor in accident prevention in that it limits the injury to a worker if caught between the rolls."[56] As a result, current ANSI standards B28.1-1967 and P1.1-1969 continue to include specific standards language describing devices to use, locations, and limits of travel for rolls (after emergency stop device activation). This is an important exception with current consensus standards regarding emergency stopping devices.

Similar references to emergency stopping devices can be found in many other ANSI standards. Currently, there are over 10,000 standards approved by ANSI.[57] Some important ones have been selected and the following excerpts are included for relevant information:

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[55]Safety Code for Rubber Mills and Calenders, B28-1927 (New York, 1927), pp. 3-4, 10.

[56]Ibid., p. 10.

[57]American National Standards for Safety and Health 1983-84 Catalog (New York, 1983), p. 2.

Z53.1-1979 - Color Code for Marking Physical Hazards

3. Purpose

The intent of this standard is to establish
a safety color code that will alert and inform
persons to take precautionary action or other
appropriate action in the presence of hazards.

4. Applications

4.1 The criteria of this standard shall apply to
the use of safety color coding for the identifi-
cation of physical hazards, the location of safe-
ty equipment, protective equipment, stationary
machinery, portable powered hand tools, signs,
and markers.

6. Color Meaning

6.1 Safety Red. Safety red shall be the color for
the identification of (1) Danger; (2) Stop.

The following are examples of applications of the
color Safety Red:

(1) Emergency stop bars on hazardous machines
(2) Stop buttons or electrical switches used for
emergency stopping of machinery

7. Color Specification and Test Methods

7.1 Visual

7.1.1 The primary color specification is in terms
of the Munsell Notation System, a color identifi-
cation and specification system based on equal
visual spacing as described in American National
Standard Method of Specifying Color by the Munsell
System, ANSI/ASTM D 1535-68 (Z138.5)....

7.5 Color Blindness. The colors in the Combined
Standard Safety Color Code have been chosen to give
maximum feasible recognition to both normal and
color-deficient (specifically red-green confusing)
observers.[58]

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[58]Safety Color Code for Marking Physical Hazards,
Z53.1-1979 (New York, 1979), pp. 5-10.

B20.1-1984 - Conveyors and Related Equipment

5.11.2 Control Station

(a) Control stations should be so arranged and located that the operation of the equipment is visible from them, and shall be clearly marked or labeled to indicate the function controlled.

(c) Remotely and automatically controlled conveyors, and conveyors where operator stations are not manned or are beyond voice and visual contact from drive areas, loading areas, transfer points, and other potentially hazardous locations on the conveyor path not guarded by location, position, or guards, shall be furnished with emergency stop buttons, pull cords, limit switches, or similar emergency stop devices.

(1) All such emergency stop devices shall be easily identifiable in the immediate vicinity of such locations unless guarded by location, position, or guards. Where the design, function, and operation of such conveyor clearly is not hazardous to personnel, an emergency stop device is not required.

(2) The emergency stop device shall act directly on the control of the conveyor concerned and shall not depend on the stopping of any other equipment. The emergency stop devices shall be installed so that they cannot be overridden from other locations.[59]

01.1-1975 - Woodworking Machinery

5.1.3 Machine Control

5.1.3.1 Each machine, whether mechanically or electrically driven, shall be provided with a device that will make it possible for the operator to cut off the power supply to the machine without leaving his normal operating position.

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[59]Safety Standard for Conveyors and Related Equipment, B20.1-1984 (New York, 1984), p. 8.

5.1.3.5 Power controls and operating controls
shall be located within easy reach of the op-
erator while he is at his regular work station.
They shall be positioned so as to make it un-
necessary for him to reach over a hazardous
area to actuate the control.[60]

Z245.5-1982 - Baling Equipment

4 Construction and Modification Requirements

4.1.1.3 Controls. Each operator control shall
be conspicuously labeled as to its function.
Operating controls shall be designed and located
to prevent unintentional activation.

4.1.1.3.2 Stop buttons and emergency stop buttons
shall be red, distinguishable from all other con-
trols by size and color, and shall not be recessed.

4.1.1.5 Emergency Stop. A means of stopping and
controlling the movement of the ram at any point
shall be provided. For multiple-stage balers, an
emergency stop mechanism shall be provided to stop
all rams. Located next to this mechanism shall be
reverse mechanisms, one for each ram.[61]

A90.1-1976 - Manlifts

5.8 Rope Control Stop

5.8.1 Requirements. A rope control stop means
shall be provided.

5.8.2 Location. This control shall be within
easy reach of the up and down runs of the belt,
incorporating rope guides and pulley arrange-
ments to restrict lateral movement.

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[60]Safety Requirements for Woodworking Machinery,
01.1-1975 (New York, 1975), p. 9.

[61]Safety Requirements for Baling Equipment,
Z245.5-1982 (New York, 1982), p. 8.

5.8.3 Operation. This control shall be so connected to a control lever or operating mechanism that it will cut off the power and apply the brake when pulled in the direction of travel.

5.8.4 The control shall consist of rope with a diameter not less than 3/8 inch (9.525 mm). Wire rope shall not be used.[62]

Z245.1-1975 - Refuse Collection and Compaction Equipment

7. Specific Mobile Equipment Safeguards and Features

7.1 Front-Loading Compaction Equipment

7.1.4 Controls

7.1.4.1 Each control shall be conspicuously labeled as to its function.

7.1.4.2 Controls for operating the container-lifting mechanism, packer panel, and tailgate shall be designed and located to prevent unintentional activation.

7.1.4.3 All controls for operating any part of the container-lifting mechanism shall be dead-man controls.

7.3 Rear-Loading Compaction Equipment

7.3.3 Controls

7.3.3.1 Each control shall be conspicuously labeled as to its function.

7.3.3.2 Controls (for example, for operating the packer panel, tailgate, point of operation guards, ejector panel, container hoists) shall be designed and located to prevent unintentional activation.

7.3.3.2.1 Start buttons shall be recessed or located to prevent unintentional activation.

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[62]*Safety Standard for Manlifts*, A90.1-1976 (New York, 1976), p. 17.

7.3.3.2.2 Stop button controls shall be red, distinguishable from all other controls by size and color, and not be recessed.

7.3.3.5 For emergencies a means of stopping and moving the packer panel away from the pinch point (prior to the pinch point) shall be provided. Emergency stop controls shall be red, distinctly labeled as to function, and not be recessed.[63]

Standards Summary: Useful Recommendations

Although the development of ANSI standards seems to have been done by separate committees working in response to specific hazards in different industries, many worthwhile recommendations can be gleaned from them. In reviewing the standards and viewpoints from personal correspondences previously mentioned, the following recommendations with regard to emergency stopping devices can be made:

(1) The master stop control should be located in the same place on each master control panel.

(2) A red colored control should be used consistently for the emergency stopping device and other controls should not be coded red.

(3) Momentary operation of the device should immediately stop hazardous motion and leave the

[63]Safety Requirements for Refuse Collection and Compaction Equipment, Z245.1-1975 (New York, 1975),pp. 17-18.

system in a safe condition.

(4) Restarting of machinery should require use of a separate and distinct operation.

(5) A stop control should be available to each operator at each normal operator's station, and in each hazardous location where operators may be required to work.

(6) Means should be available for manually inching hazardous machine parts foreward or backward.

(7) If hazardous machine parts can coast after the emergency stopping device is actuated, a braking system should be incorporated to achieve good stopping performance.

(8) Controls used on similar machines should be standardized in configuration, location, function, and color coding.

(9) Emergency stopping devices should be tested frequently by making use of them during routine stopping of equipment.

(10) Emergency stopping devices should be size and shape coded.

(11) All controls should be conspicuously labeled.

(12) Emergency stop pushbuttons should not be recessed.

Legal Requirements

The previous discussion has focused on the development of voluntary consensus standards applicable to emergency stopping of industrial machines. As written, voluntary standards developed by standards setting organizations were never binding unless federal, state, or local laws incorporated them within their codes of regulations. Before the Occupational Safety and Health Act of 1970 (OSHAct, Public Law 91-596), enactment of health and safety laws had been left principally to the individual states.[64] Some federal legislation existed including: the Service Contract Act of 1965, the National Foundation on Arts and Humanities Act, the Federal Metal and Non-metallic Mine Safety Act, and the Contract Workers and Safety Standards Act (Construction Safety Act), but these were applicable only to a limited number of employees such as those who worked on federal contracts or in specific industries.[65] The rest were covered only by state laws and each state had a different set of health and safety regulations which might have included codes derived from many different sets of consensus standards. Not only did these standards vary from one state to another but regulations were often lax, inadequate, and ineffectively enforced.[66]

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[64]McElroy, p. 21.   [65]Ibid.   [66]Ibid.

One major concern of the federal OSHAct was, "...to assure so far as possible every working man and woman in the Nation safe and healthful working conditions..."[67] One of the ways this objective was accomplished was in setting mandatory Occupational Safety and Health standards and requiring compliance by employers and employees. Many previously issued consensus standards were compiled, revised where necessary, and used as the basis for OSHA standards.[68] Current OSHA regulations that apply to emergency stopping devices are found in the Occupational Safety and Health Standards for General Industry (29 CFR Part 1910). The following excerpts from this document apply to emergency stopping of machines and emergency stop devices:

Subpart O -- Machinery and Machine Guarding

1910.211 Definitions

(52) "Stop control" means an operator control designed to immediately deactivate the clutch control and activate the brake to stop slide motion.

1910.212 General requirements for all machines

(No entries applicable to emergency stops)

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[67]Occupational Safety and Health Act of 1970, Public Law 91-596 (Washington, D.C., 1970), p. 1.

[68]McElroy, p. 27.

1910.213 Woodworking machinery requirements

(b) Machine controls and equipment.
(1) A mechanical or electrical power control
shall be provided on each machine to make it
possible for the operator to cut off the power
from each machine without leaving his position
at the point of operation.

(4) Power controls and operating controls should
be located within easy reach of the operator while
he is at his regular work location, making it un-
necessary for him to reach over the cutter to make
adjustments...

1910.214 Cooperage machinery

(Revoked at 43 F.R. 49726, October 24, 1978)

1910.215 Abrasive wheel machinery

(No entries applicable to emergency stops)

1910.216 Mills and calenders in the rubber and
plastics industries.

(b) Mill safety controls --- (1) Safety trip control.
A safety trip control shall be provided in front and
in back of each mill. It shall be accessible and
shall operate readily on contact. The safety trip
control shall be one of the following types or
a combination thereof:

(i) Pressure-sensitive body bars. Installed at
front and back of each mill having a 46-inch roll
height or over. These bars shall operate readily
by pressure of the mill operator's body.

(ii) Safety triprod. Installed in the front and in
the back of each mill and located within 2 inches
of a vertical plane tangent to the front and rear
rolls. The top rods shall be not more than 72
inches above the level on which the operator stands.
The triprods shall be accessible and shall operate
readily whether the rods are pushed or pulled.

(iii) Safety tripwire cable or wire center cord.
Installed in the front and in the back of each mill
and located within 2 inches of a vertical plane
tangent to the front and rear rolls. The cables
shall not be more than 72 inches above the level on
which the operator stands. The tripwire cable or
wire center cord shall operate readily whether cable
or cord is pushed or pulled.

(c) Calender safety controls --- (1) Safety trip, face. A safety triprod, cable, or wire center cord shall be provided across each pair of in-running rolls extending the length of the face of the rolls. It shall be readily accessible and operate whether pushed or pulled. The safety tripping devices shall be located within reach of the operator and the bite.

(2) Safety trip, side. On both sides of the calender and near each end of the face of the roll, there shall be a cable or a wire center cord connected to the safety trip. They shall operate readily whether pushed or pulled.

(e) Trip and emergency switches. All trip and emergency switches shall not be of the automatically re-setting type, but shall require manual resetting.

1910.217 Mechanical power presses

(b) Mechanical power press guarding and construction.

(7) Machines using part revolution clutches

(ii) A red color stop control shall be provided with the clutch/brake control system. Momentary operation of the stop control shall immediately deactivate the clutch and apply the brake. The stop control shall override any other control, and reactuation of the clutch shall require use of the operating (tripping) means which has been selected.

(8) Electrical. (i) A main power disconnect switch capable of being locked only in the Off position shall be provided with every power press control system.

(ii) The motor start button shall be protected against accidental operation.

1910.218 Forging machines

(No entries applicable to emergency stops)

1910.219 Mechanical power transmission apparatus

(No entries applicable to emergency stops)

Subpart R -- Special Industries

1910.261 Pulp, paper, and paperboard mills.

(c) Handling and storage of pulpwood and pulp chips.

(15) Belt conveyors.

(iv) Every belt conveyor shall have an emergency stop cable extending the length of the conveyor so that it may be stopped from any location along the line, or conveniently located stop buttons within 10 feet of each work station, in accordance with American National Standard B20.1-1957.

(k) Machine room.

(1) Emergency stops. Paper machines shall be equipped with devices that will stop the machine quickly in an emergency. The devices shall consist of push buttons for electric motive power (or electrically operated engine stops), pull cords connected directly to the prime mover, control clutches, or other devices, interlocked with adequate braking action. The devices shall be tested periodically by making use of them when stopping the machine and shall be so located that any person working on the machine can quickly disconnect the machine from the source of power in case of emergency.

(1) Finishing rooms.

(2) Emergency stops. Electrically or manually operated quick power disconnecting devices, interlocked with braking action, shall be provided on all operating sides of the machine within easy reach of all employees. These devices shall be tested by making use of them when stopping the machine.

(7) Rotary cutter.

(v) Electrically or manually operated quick power disconnecting devices with adequate braking action shall be provided on all operating sides of the machine within easy reach of all operators.

1910.262 Textiles.

(c) General safety requirements.

(1) Means of stopping machines. Every textile machine shall be provided with individual mechanical or electrical means for stopping such machines....

(h) Slashers.

(1) Cylinder dryers.

(iv) Pushbutton control. Slashers operated by pushbutton control shall have start and stop buttons located at each end of the machine, and additional buttons located on both sides of the machine, at the size box and the delivery end. If calender rolls are used, additional buttons shall be provided at both sides of the machine at points near the nips, except when slashers are equipped with an enclosed dryer.

(2) Enclosed hot air dryer.

(ii) Push-button control. Slashers operated by push-button control shall have one start button at each end of the machine and stop buttons shall be located on both sides of the machines at intervals spaced not more than 6 feet on centers....

(aa) Sanforizer and palmer machine. A safety trip rod, cable, or wire center cord shall be provided across the front and back of all palmer cylinders extending the length of the face of the cylinder. It shall operate readily whether pushed or pulled. This safety trip shall be not more than 72 inches above the level on which the operator stands and shall be readily accessible.

(bb) Rope washers.

(2) Safety stop bar. A safety trip rod, cable or wire center cord shall be provided across the front and back of all rope washers extending the length of the face of the washer. It shall operate readily whether pushed or pulled. This safety trip shall be not more than 72 inches above the level on which the operator stands and shall be readily accessible.

1910.263 Bakery equipment.

(e) Mixers.

(1) Horizontal dough mixers.

(iii) Each mixer shall be equipped with an individual motor and control,...

(g) Moulders.

(3) Stopping devices. There shall be a stopping device within easy reach of the operator who feeds the moulder and another stopping device within the reach of the employee taking the dough away from the moulder.

(h) Manually fed dough brakes.

(2) Emergency stop bar. An emergency stop bar shall be provided, and so located that the body of the operator will press against the bar if the operator slips and falls toward the rolls, or if the operator gets his hand caught in the rolls. The bar shall apply the body pressure to open positively a circuit that will deenergize the drive motor. In addition, a brake which is inherently self-engaging by requiring power or force from an external source to cause disengagement shall be activated at the same time causing the rolls to stop instantly. The emergency stop bar shall be checked for proper operation every 30 days.

(i) Miscellaneous equipment.

(7) Conveyors.

(iii) Where hazard of getting caught exists a sufficient number of stop buttons shall be provided to enable quick stopping of the conveyor.

(1) Ovens.

(3) Safeguards of mechanical parts.

(i) Emergency stop buttons shall be provided on mechanical ovens near the point where operators are stationed.[69]

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[69] Occupational Safety and Health Standards for General Industry (Chicago, Illinois), pp. 189-286.

As can be seen from these entries, federal regulations covering emergency stopping devices on industrial machines have generally been extracted from those consensus standards covering processes where there has been a long established need for such devices and a strong emphasis on the emergency stop within the standard (such as on mills and calenders). In those areas such as mechanical power transmission where there is currently no emphasis on emergency stopping of equipment within the consensus standard, there is also no federal regulatory requirement. Furthermore, within the general requirements for all machinery (29 CFR 1910.212) there is no reference made to an emergency stopping device nor the need for providing the capability to quickly stop machines. It appears that the importance of quickly stopping equipment during emergencies has not been recognized or has somehow been ignored; it is not a consistent, mandatory federal requirement.

Military Standards

Military standards have often proved to be very specific and detailed when specifying equipment requirements. Perhaps this results due to a need for consistency among many thousands of units purchased and from a desire to advantageously apply ergonomic principles. It is expected that military personnel may engage in life-threatening activities and this is how they are trained. In order

for soldiers to respond quickly and effectively under
emergency situations they are conditioned with the de-
sired response and this is reinforced through frequent
practice. Furthermore, the advantage of reinforcing
prelearned human expectancies cannot be ignored. Man-
ipulation of controls is a function humans learn from a
very young age and it would not be sensible to violate
long established expectancies between control movements
and system response. Therefore, a significant emphasis
on machine controls has been included in manuals of mili-
tary specifications. The following excerpts from the
Military Standard Human Engineering Design Criteria for
Military Systems, Equipment and Facilities, MIL-STD-1472C
are applicable to emergency stopping devices:

5.4.1.3 Arrangement and Grouping.

5.4.1.3.3 Location of Primary Controls. The most
important and frequently used controls shall have
the most favorable position with respect to ease
of reaching and grasping...

5.4.1.3.4 Consistency. The arrangement of function-
ally similar, or identical, primary controls shall
be consistent from panel to panel throughout the
system, equipment, or vehicle,...

5.4.1.4 Coding.

5.4.1.4.1 Methods and Requirements. The use of a
coding mode (e.g., size and color) for a particular
application shall be governed by the relative ad-
vantages and disadvantages of each type of coding.
Where coding is used to differentiate among controls,
application of the code shall be uniform throughout
the system...

5.4.1.4.2 <u>Location Coding</u>. Controls associated with similar functions should be in the same relative location from operator work station to work station and from panel to panel.

5.4.1.4.3 <u>Size-Coding</u>. No more than three different sizes of controls shall be used in coding controls for discrimination by absolute size. Controls used for performing the same function on different items of equipment shall be the same size...

5.4.1.4.4 <u>Shape-Coding</u>. Primary use of shape coding for controls is for identification of control knobs or handles by "feel;" however, shapes shall be identifiable both visually and tactually...

5.4.1.4.5 <u>Color-Coding</u>.

5.4.1.4.5.1 <u>Choice of Colors</u>. Controls shall be black (17038, 27038, or 37038) or gray (26231 or 36231). If color coding is required, only the following colors identifiable by FED-STD-595 shall be selected for control coding.

     a. Red, 11105, 21105, 31105
     b. Green, 14187
     c. Orange-Yellow, 13538, 23538, 33538
     d. White, 17875, 27875, 37875
     e. Blue, 15123 shall be used if an additional color is absolutely necessary.

5.4.1.4.5.4 <u>Control Panel Contrast</u>. The color of the control shall provide contrast between the panel background and the control.

5.4.1.8 <u>Prevention of Accidental Activation</u>.

5.4.1.8.3 <u>Rapid Operation</u>. Any method of protecting a control from inadvertent operation shall not preclude operation within the time required.

5.4.3 <u>Linear Controls</u>.

5.4.3.1 <u>Discrete Linear Controls</u>.

5.4.3.1.1 <u>PushButtons (Finger or Hand Operated)</u>.

5.4.3.1.1.1 <u>Use</u>. Push buttons should be used when a control or an array of controls is needed for momentary contact or for activation of a locking circuit, particularly in high-frequency-of-use situations.

5.4.3.1.1.2 <u>Shape</u>. The push button surface should normally be concave (indented) to fit the finger. When this is impractical, the surface shall provide a high degree of frictional resistance to prevent slipping.[70]

The following excerpts applicable to emergency stopping devices are from the <u>Military Handbook Human Factors Engineering Design for Army Material</u>, MIL-HDBK-759A(MI):

1.1 CONTROLS.

1.1.1 <u>General Criteria</u>

1.1.1.3 <u>Arrangement and Grouping</u>

1.1.1.3.1 <u>Primary Controls</u> - The most important and frequently used controls should have the most favorable positions with respect to ease of reaching and grasping...

1.1.1.3.4 <u>Emergency Controls</u> - Emergency function controls should be located where they can be identified and reached quickly. However, their location should not be such that accidental use or inadvertent contact could result in serious system malfunction and/or ultimate injury to personnel.

1.1.1.3.5 <u>Consistency</u> - When functionally similar control interfaces appear in more than one operator station within the same or similar systems, control locations and arrangements should also be the same or at least similar.

1.1.1.4 <u>CODING</u>.

1.1.1.4.1 <u>Factors to be Considered</u>. Many methods of coding are available. The choice of coding should be based on such factors as:

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[70]<u>Military Standard Human Engineering Design Criteria for Military Systems, Equipment and Facilities</u>, MIL-STD-1472C (Washington, D.C., 1981), pp.64-69, 84, 87.

(a) Types of coding already being used.

(b) Kinds of information to be used.

(c) Nature of the tasks to be performed, and the conditions under which they will be performed

(d) Number of coding steps or categories available (e.g., the number of different knob shapes available, and how many of those shapes users can discriminate easily).

(e) Need for redundant or combination coding.

(f) Standardizing coding methods.

Any coding method that is selected should be used consistently, and with consistent meaning, throughout the system. Consideration should be given to coding used in other systems which the operator may be employed (either separately from or in conjunction with the system being designed). The method should allow controls to be identified easily by sight or touch and discrimination from each other by color, size, shape and location.

1.1.1.4.2 Color.

1.1.1.4.2.3 Emergency Controls. All emergency controls should be coded red. To give these emergency controls the visual emphasis they demand, only a bare minimum of other, less important controls should be color coded. Colors used to code critical controls should contrast sharply with those used for non-critical controls.

1.1.1.4.2.5 Control-Panel Contrast. Control color should contrast with the panel on which they are mounted.

1.1.1.4.3 Shape.

1.1.1.4.3.1 Design Coding - The primary reason for shape coding controls is to facilitate identification by "feel." However, shapes should be identifiable both visually and tactually. When shape coding is used, the coded feature should not interfere with the ease of control manipulation. Shapes should be equally identifiable regardless of the position of the control knob or handle,...

1.1.1.4.3.2 Similar Functions. Controls with similar purposes or functions should have the same shape.

1.1.1.4.3.3 <u>Dimensions</u>. When operators must distinguish controls by touch alone, the shape of the control should be free of sharp edges or corners and at least:

    (a) Height: 13 mm or larger

    (b) Width: 13 mm or larger

    (c) Depth: 6.5 mm or larger

1.1.1.4.4 <u>Size</u>.

1.1.1.4.4.1 <u>Discrimination of sizes</u>. When coding controls by size, it is important to make sure sizes differ enough that users are not likely to confuse them. Users can learn to discriminate two or three different sizes of controls; if more coding steps are needed, another coding system should be used. When coding knobs with diameters between 13 mm and 100 mm by size, each knob's diameter should be at least 20% larger than the next smaller one.

1.1.1.4.4.2 <u>Similar Functions</u>. Code sizes should be consistent when controls have similar functions on different items of equipment.

1.1.1.5 <u>Labels</u>.

1.1.1.5.1 <u>General</u>. Controls should have labels (on panel or control) that:

    (a) Identify what they control.

    (b) Show how to operate the control.

1.1.10 <u>Push Button Switches (Hand-Operated)</u>

1.1.10.1 <u>Application</u> - Push button controls should be used primarily when a simple switching between two conditions are required, selection of alternate on-off functions from an array of related conditions, or subsystems functions,...

1.1.10.5 <u>Push Button Cap Shape</u> - Cap surfaces should, in general, be flat, but with rounded edges. However, for proper finger centering, which must be insured, the cap surface may be concave. General cap shapes may be round, square, or rectangular as long as they provide adequate finger, thumb or hand contact area, and are compatible with identification or legend requirements.

1.3.6 <u>Control/Display Integration</u>.

1.3.6.6 <u>Importance of Use</u>. Controls and displays which are critical to operation should be placed in preferential positions...

1.3.6.8 <u>Emergency Use</u>. Emergency displays and controls should be located where they can be seen and reached with minimum delay (e.g., warning lights within a 30-degree cone about the operator's nominal line of sight; emergency controls close to the nearest available hand in its nominal operating position.[71]

Military Standards Summary

As can be seen from these excerpts, military requirements for system controls are very much influenced by human factors principles (ergonomics). The relationships of human factors to emergency response are covered in detail in chapter III so they will not be examined here. However, some important principles can be gleaned from these military requirements; in review, the following recommendations with regard to emergency stopping devices can be made:

(1) The most important controls, including emergency controls, should have the most favorable positions on a control panel.

(2) Consistency in location, size, and shape should

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[71]<u>Military Handbook Human Factors Engineering Design For Army Material</u>, MIL-HDBK-759A(MI) (Washington, D.C., 1981), pp. (1-1), (1-7)-(1-12), (1-43), (1-49), (1-168), (1-173).

be maintained from panel to panel throughout each system.

(3) Consistency between systems is highly desirable.

(4) No more than three different sizes of controls should be used.

(5) Emergency controls should be coded red.

(6) A minimum of other controls should be color coded to provide emphasis to emergency controls. Most controls should be black or gray.

(7) Control panels should be colored to provide good contrast with controls.

(8) Methods of protecting controls from inadvertent activation should not impair operation within the time required.

(9) Pushbuttons should be shaped to fit the finger/ hand or surfaces should provide a good grip.

(10) Shape coded controls should be discriminable both visually and tactually.

(11) Minimum pushbutton size for tactual discrimination should be 13 mm (each edge, diameter, etc.) and 6.5 mm in depth.

(12) Size coded controls should be limited to three different sizes. Each knob diameter should be 20% or more larger than the next smaller diameter.

(13) Controls should be labeled.

CHAPTER III

HUMAN FACTORS AFFECTING AN EMERGENCY RESPONSE

Response Time: Human-Machine Systems

The question: how fast can a human being respond in
an emergency is universally asked. Everyone working under
the forces of nature or the laws of physics governing man-
made machines needs to respond to changing environmental
and mechanical conditions. In normal daily events there
might not be any life-threatening emergency requiring an
immediate response; and no one needs to know exact times
required to perform mundane tasks, but a general under-
standing of human limitations, especially the delays that
occur within a human-machine system during emergency re-
sponse is required.

After many accidents a statement is made regarding
what should have been done to prevent the damage. Often
these comments seem ridiculous in contrast with the seri-
ous effects of the event, but the notion that "hindsight
is clearer than foresight" does present one important con-
cept: the realization that if someone had reacted correct-
ly before some critical time, the disaster could have been
avoided, or loss and suffering could have been minimized.
In other words, there is always some time period during
which a correct response can change the outcome of an

impending disastrous event. Machines can be stopped before they break down. Water can be drained before a dam breaks and towns can be evacuated before a volcano erupts. Clearly, the question then becomes: does the human being in a position to avert this disaster have the ability to recognize the danger and the time to make the correct decision and respond?

Any human emergency response assumes that the following processes have occurred: receptor stimulation, neural conduction to the brain, perception and recognition, neural conduction to the muscles, and muscular contraction.[72] These activities take time. "The human operator has a limited response speed, frequency, and flexibility."[73] In effect there is a minimum time delay that can be expected from any person required to detect an input signal, process the information, select a course of action, and complete the required physical motions. This is known as the response speed. There is also a limitation to the frequency of data input that can be analyzed and the number of responses that can be made from that data in any increment of time. Lastly, human flexibility is limited in the number of sensory channels that can be simultaneously processed (i.e., audible, visible, tactile, etc.).[74]

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[72]Michael J. Wargo, "Human Operator Response Speed, Frequency, and Flexibility: A Review and Analysis," Human Factors,9(3) (June, 1967),223.

[73]Ibid., p. 221.   [74]Ibid.

Total response time of any human-machine system has been reported to consist of various delays and lags that are operator and system imposed; these are:

(1) Display lags and delays

(2) Human input acquisition and receptor delays

(3) Neural transmission delays

(4) Central processing delays

(5) Muscle activation time

(6) Movement time

(7) System dynamics lags and delays[75]

Items (1) and (7) represent delays that result due to the mechanical and electrical characteristics of the system design. Items (2) through (6) represent delays that result due to the human factor in the human-machine system and these must be considered in the design of any emergency controls.

Operator Delays During Response to Emergency Stimuli

Human input acquisition and receptor delays occur as a function of the person's level of vigilance, the form, intensity, quality, and surround of the input signal, and as a function of the chemical/electrical transduction pro-

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[75]Wargo, p. 222.

cess of the particular sense organ.[76]

Neural transmission delays occur as a result of the time required for neural impulses to traverse the chain of individual nerve cells (neurons). This is a biochemical energy conversion process. For any human stimulus-response action two neural transmissions are required: the afferent, the impulse that travels from the receptor to the cerebral cortex, and the efferent that travels from the cortex to the voluntary muscles.[77] Delays occur as a function of fiber composition, diameter, length, and the number and complexity of synaptic connections.[78]

Central processing delays occur as a result of the time required to perceive, recognize, discriminate, and identify a particular emergency situation as different from the norm.[79] These are the result of the thinking and decision making processes and generally are the most variable. When the complexity of the situation increases such as when there is a choice of responses that can be made, the time required for central processing can increase dramatically.[80]

Muscle activation time is defined by Wargo as the time required for peak muscle tension to be developed after the myoneural junction is stimulated.[81] This time is known to vary as a function of muscle type, mass, and

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[76]Wargo, p. 223.   [77]Ibid.   [78]Ibid.

[79]Ibid., p. 224.   [80]Ibid.   [81]Ibid.

innervation (the arrangement or disposition of nerves within the muscle).[82]

Movement time occurs as a result of the distance between the body part to be used for control and the control device. Delays occur as a function of distance, muscle activation time, mass of the body part, inertia, and design of the control device. Frequently, movement time is divided into two segments: the time required to complete the gross movement, and the time to make fine adjustments; these would be designated "primary" and "secondary" movements.[83] Wargo estimates that primary movements tend to reduce error to within 10% and secondary movements to within 1% of the original distance; a minimum movement time of 0.3 second can be expected when making even a one inch motion with the hand, more than half the total response time.[84]

Reaction Time Experiments

In laboratory experiments the simple reaction time (RT) is defined as the time lag between stimulus onset and the first visible sign of a response (i.e., the first detectable movement).[85] Movement time is excluded. The disjunctive or choice reaction time is defined as the time

[82]Wargo, p. 224.   [83]Ibid., p. 233.   [84]Ibid.
[85]Ibid., p. 225.

lag between stimulus onset and first visible sign of response when the correct response depends on which of a variety of stimuli is presented.[86] For example: if the presentation of a red or green colored light means that a subject should press a corresponding red or green emergency stop button, this would be a choice reaction time measurement. Wargo summarizes operator delays for the simple and choice reaction times as follows:[87]

Delay Basis	One Choice	Disjunctive
Receptor Delays	1-38	1-38
Afferent Transmission Delays	2-100	2-100
Central Process Delays	70-100	90-300
Efferent Transmission Delays	10-20	10-20
Muscle Latency and Activation Time	30-70	30-70
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Reaction Time or Total Delay	113-328	133-528

(Times in milliseconds)

As can be seen from the table the best simple reaction time that could be expected of an experimental subject

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[86]Wargo, p. 225. [87]Ibid., p. 224.

would be approximately 0.113 second. Furthermore, Wargo's estimate presupposes that the subject is trained, in position for the response, and also is prewarned a few seconds prior to stimulus presentation; a situation that could hardly be expected under actual emergency conditions. It would be difficult to guess how an industrial operator might compare with these estimates when reacting under an actual emergency condition. It is likely that they have other jobs to do besides vigilance of emergency stopping procedures. They must observe, control, and record many operating parameters during a shift; therefore, an awareness of impending crisis cannot be assumed and the operator could not be expected to have his/her hand resting on the control device prior to the emergency signal.

Receptor delays, neural transmission time, and muscle activation time are factors that would not be expected to vary significantly with subjects performing multiple experimental trials or industrial operators. These delays are functions of the transduction process at the receptor level, the composition and length of particular nerves in the neural pathway, and the rate of biochemical information transmission. Therefore, it would not be expected that any operator training or practice could affect these in any significant way. Central processing delays and movement delays on the other hand would be expected to vary with many factors, such as: the operator's cognizance of the emergency situation, previous training, position

with respect to the control, personal activity, and the design of the control device. With individuals performing multiple experimental trials the effects of practice and fatigue would be expected to affect experimental results.

Simulating Uncertainty

When testing human responses to emergency signals, subjects often perform under minimum uncertainty. They know what signal to expect and the required response. Experimenters place subjects where response is made easy and movements are practiced in advance. The emergency is not real and no damage occurs if subjects respond incorrectly or too slowly. As a result, motivation during testing conditions cannot approach the level encountered in a crisis where panic can affect the outcome. Often there is no real comparison between a test subject's response and the response of an accident victim. A subject knows that it's only a test, but a frightened worker caught in a machine instantly senses the danger; a correct response in the latter case is imperative, it may save life or limb. Can a stop button even be reached? Perhaps not.

A major problem when studying human emergency response is how to experimentally produce sufficient uncertainty to provide meaningful results. Time uncertainty

is the only variable that can be easily controlled by an
experimenter and it is by definition the only uncertainty
a subject has during simple reaction time tests.[88] Un-
certainty results due to subjects' imperfect internal
clocks and variability of stimulus presentation. In a
classic experiment Klemmer studied the relationship be-
tween reaction time and subjects' uncertainty about time
of stimulus presentation.

In a first series of tests a prestimulus warning
click was given at eleven second intervals with the stim-
ulus flash (neon light) presented thereafter. The time
period between click and flash was designated the "fore-
period" and foreperiod mean and variability were changed
between tests. In a second series of tests no prestimulus
warning was given at all and stimuli were presented at
identical intervals during each sequence of trials. Inter-
stimulus intervals were then changed for later sequences.

The results showed two important human tendencies:

(1) Reaction time increases with foreperiod vari-
    ability and with mean foreperiod above some
    small optimum value (less than one second).

(2) It is not the immediate foreperiod that dra-
    matically affects reaction time but the dis-

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[88]Edmund T. Klemmer, "Time Uncertainty in Simple
Reaction Time," Journal of Experimental Psychology, 51(3)
(1956), 179.

tribution of foreperiods in which it occurs.[89]

It is doubtful that these short-term observations could be extrapolated to explain human response during very long interstimulus intervals that would be expected for emergencies. Even in those industries that require frequent emergency stops of machines due to jams, mis-feeding of stock, mis-alignments, etc., interstimulus intervals would likely be measured in minutes or hours rather than seconds as in Klemmer's experiment. In any event, there is one clearly established factor: that ex-pectation can influence a person's state of readiness and can potentially shorten response time. In an industrial setting such prestimulus warnings could occur as changes in pitch of machine sounds, increased vibrations, gauge changes, etc., and these could warn an alert operator to an impending emergency. However, there is no guaranty that this will occur; a sudden entanglement in a machine might occur without any conscious expectation.

Human Expectation in Emergencies

This problem of expectation was studied by Johansson and Rumar who tested automobile drivers' response to emer-

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[89]Klemmer, p. 184.

gency signals.[90] The purpose of the experiment was two-fold. First they wanted to obtain a correction factor to be applied to brake reaction time data for estimating the difference between situations where braking is expected and unexpected. Second they wanted to determine the distribution of a random sample of drivers when the drivers knew they would be required to brake their vehicles suddenly at some time between two check-points.

The experiment was performed in two parts. During the first part drivers of vehicles along a chosen road were stopped by police and asked if they would participate in the experiment. If they agreed, they were told that at some time during their next ten kilometers of travel they would hear a loud horn and at that signal they were to immediately step on the brake. They were not to completely stop their cars but when the horn stopped they were to release the brake and continue on their way. The horn signal was initiated by an experimental assistant located five kilometers up the road. The assistant recorded the reaction time of each driver by pressing a stop key at the instant the vehicle's brake lights were seen. The human variability of the assistant was estimated at less than 4% of total recorded variability and his mean response time was subtracted from each

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[90]Gunnar Johansson and Kare Rumar, "Drivers' Brake Reaction Times," <u>Human Factors</u>, 13(1) (February, 1971), 23-27.

of the data.

For the second part of the experiment, five experienced drivers who had also participated in the first phase of the experiment were chosen. Each driver's vehicle was fitted with an electronic timer that would initiate an alarm signal (buzzer) and record the elapsed time for a braking response. The interstimulus intervals were set to be in excess of one hour and, since the cars were used mostly for short trips, drivers did not know during which trip a signal could be expected; intersignal variability was known to be from a minimum of about one hour to a maximum of more than a week which depended solely on the car's use.

The results showed that the histogram of reaction times for 321 expectant drivers (first phase of the experiment) had a positively skewed appearance, although the authors did not report this observation. The median brake reaction time was 0.66 second with a range of 0.3 to 2.0 seconds. Mean reaction time was not reported but can be estimated at about 0.74 second from the histogram supplied.[91]

For part two of the experiment all five drivers tested showed longer brake reaction times when the signals occurred unexpectedly; however, it appears that the authors did not test for statistical significance between

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[91]Johansson and Rumar, pp. 25-26.

means, preferring rather to work with observed medians.
A correction factor was computed from the data and indi-
cated that the unalerted brake reaction time would be
about 1.35 times longer than the alerted time.[92]

Due to the small number of drivers used for part two
of the experiment, and the authors' lack of rigor in sta-
tistical testing it is questionable if the data obtained
show truly significant differences between the expectant
and unexpectant conditions. However, the fact that the
distribution obtained in part one appears to be positive-
ly skewed is worth noting. The question might be asked:
is the observed skewness of drivers' reaction times re-
lated to expectancy? In other words, when comparing re-
sponse time distributions from the expectant and unexpec-
tant parts of this experiment would it be found that the
unexpectant case is more positively skewed? Unfortunate-
ly the authors did not supply the distribution of data
from part two of the experiment so this comparison can-
not be made.

The answers to these questions could provide some
insight into how humans respond under true emergency con-
ditions. Real emergencies often occur with near zero ex-
pectancy (i.e., they are almost totally unexpected).
Those persons who know what to do respond immediately;
those who don't know, hesitate. Still others may freeze.

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[92]Johansson and Rumar, p. 26.

Therefore, it seems that the distribution of human response times for unexpected occurrences should be skewed.

Infrequent Stimuli

Since emergency response appears to be highly dependent on human expectation and previous training the questions remain: how is response affected when stimuli occur very infrequently? What improvements could be seen if subjects were conditioned to respond over an extended time period? Warrick, Kibler, and Topmiller approached these questions by asking secretaries to press a one inch diameter pushbutton as quickly as possible after hearing an emergency buzzer.[93] The buttons were located at the lower left sides of the typewriters and identical arrangements were made for five secretaries. The signal intensity was measured to be at least thirteen decibels above background noise level while typing but it was determined by the experimenters that the sound did not elicit "startle response."

The experiment lasted over 120 working days and each subject received 48 signals at random times. Of the 48 signals only 36 were presented while secretaries were actually typing and responses to these were used as data.

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[93]Melvin J. Warrick, Austin W. Kibler, and Donald A. Topmiller, "Response Time to Unexpected Stimuli," Human Factors, 7(1) (February, 1965), 81-86.

The other responses were discarded; their inclusion in
the experiment served to increase temporal uncertainty.
Signals were presented with a mean interstimulus inter-
val of 2.5 days and a standard deviation of 1.73 days.
Also, as part of the experiment, two sets of control
trials were run in blocks of twenty trials; this was done
at the end of every twenty working days. One set was run
with the women typing but they were alerted two to five
seconds ahead of signal presentation. The other set was
run with the same alerted condition but subjects had
their fingers resting lightly on the stop buttons.

The results indicated a slight but consistent im-
provement in performance over the six month duration of
the experiment for the unexpectant condition. The 10th,
50th, and 90th percentile response times for the last six
unexpected signals were 0.51, 0.61, and 0.82 second. The
mean for all data in the unalerted condition was not giv-
en by the authors but was calculated from the frequency
distribution as 0.70 second. In considering the first
block of six trials per subject (first four weeks) as
representing minimum practice, 90% of the unalerted re-
sponse times were shorter than 1.0 second. As training
increased, the last block of six trials per subject (last
four weeks) showed 90% of the unalerted response times
were shorter than 0.8 second.[94]

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[94]Warrick, Kibler, and Topmiller, pp. 84-86.

The Startle Response

In the preceding discussion it has been seen how
temporal uncertainty and human expectation can affect
times for response to emergency signals. In general,
many observed experimental response times have been some-
what longer than Wargo estimated. Considering a reaction
time of 0.33 second (from Wargo's maximum simple reaction
time estimate) and an expected movement time of 0.30 sec-
ond for simple hand motions, the total would be 0.63 sec-
ond.[95] Nonetheless, many experiments, including the
Warrick, Kibler, Topmiller study indicate that some sub-
jects' response times to emergency signals can exceed ·
this estimate. In fact, the above authors removed one
subject's data from the computations because her response
times (median = 1.58 seconds) consistently exceeded the
90th percentile of the distribution for the other five
subjects.[96] Is it fair to assume that her data do not
represent normal expected variability within the human
population? Certainly not; but it's true her data might
seriously bias the mean of an extremely small sample (6
subjects).

Although these intersubject differences could be at-
tributed to normal human variability which might include

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[95]Wargo, pp. 224, 233.

[96]Warrick, Kibler, and Topmiller, pp. 83-84.

physical or mental differences between subjects, the pos-
sibility exists that subjects' emotional states could
also affect the response. Perhaps the above mentioned
subject was naturally slow to respond due to an unhur-
ried emotional state. In this case the alarm might not
have been sufficiently intense for her to experience the
true sensation of emergency.

It has been shown that reaction time becomes shorter
as stimulus intensity increases.[97] Furthermore, if a
subject is experiencing a continuous stimulus, it has
been shown that reaction time becomes shorter as the mag-
nitude of change in stimulus intensity increases.[98] The
most extreme example of this phenomenon could occur in an
industrial accident where stimulus intensity could in-
crease dramatically from some low level (i.e., an im-
pulse). The sudden shock of an electrical explosion
could be an example. Teichner, however, claims that the
observed decrease in response time is a non-linear
effect.[99] The question then becomes: what type of func-
tion is the response? It is here that the experimental
data are not quite clear. One possibility suggested by
Teichner is a parabolic function.[100] If this were the
case then response times could be expected to increase

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[97]Warren H. Teichner, "Recent Studies of Simple
Reaction Time," Psychological Bulletin, 51(2) (1954),
132.

[98]Ibid., p. 133.   [99]Ibid., p. 132.   [100]Ibid.

with louder or more sudden stimuli after some minimum is
reached. This could explain the freezing effect as dem-
onstrated by some persons in extreme emergencies.

Motor effects of very strong audible stimuli were
studied by Davis (i.e., the startle response).[101] In his
experiment subjects were asked to lie down and relax in a
noise-free environment. Active electrodes were placed
two to three inches above the elbows on both forearms and
normal background activity potentials were determined.
After approximately five minutes of relaxation a sudden
sound stimulus (shock wave) of 500 hertz was generated.
Three levels of approximately 90, 95, and 99 decibels
were used in the experiment. Subjects had been previous-
ly instructed to do nothing in response to the sounds.
Stimulus duration was four seconds for test A and two sec-
onds for test B.

The first test was designed to study the effects of
stimulus intensity and duration on muscular action poten-
tials while the second was to observe the effects of pre-
stimulus tension (a weight held in the hand) on the re-
sponse. The following results were obtained:

(1) The startle response consists of two distinct
responses designated by Davis as a and b.

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[101]R. C. Davis, "Motor Effects of Strong Auditory
Stimuli," Journal of Experimental Psychology, 38 (1948),
257-275.

(2) The a-response has a latency of about 0.1
second, peaks during the next 0.1 second,
and almost disappears during the next 0.5
second.

(3) The a-response rapidly adapts and practically
disappears with six or more stimulations.

(4) The a-response varies with stimulus intensity
and has a threshold below which it would prob-
ably not appear.

(5) The b-response reaches a maximum at about 1
second after stimulus onset, remains at that
level for about 1 second, and then declines
slowly.

(6) The b-response appears not to be affected by
stimulus intensity or repetition.

(7) Both a- and b-responses are related to the
state of muscular tension existing just prior
to stimulus onset.[102]

Everyone has felt the startling effect of a sudden
event so the results of Davis' work are not that surpris-
ing. But the notion that there may be two combined and
distinct responses is interesting indeed. In considering
the a-response, it is particularly short-lived and could
explain the visible jump humans emit when surprised. How-

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[102]Davis, pp. 274-275.

ever, a problem could develop with human response to startling emergencies due to tensions induced in muscles not essential for making the response. Studies of extraneous tension during reaction time have generated conflicting conclusions when relating tension to time of response.[103] The possibility exists that a startled operator might react slower if the initial shock is sufficient to elicit an a-response.

The b-response was shown to be much longer in duration and appeared to be unrelated to stimulus intensity or repetition. It could be a prolonged state of readiness to react brought on by the stimulus. Since it does not appear to die out with repetition, in those industries where operators are subjected to repeated loud sounds (a punch press operator for example), it could bring on a level of tension and annoyance incompatible with proper emergency response.

Visual Feedback

In most reaction time studies subjects respond to a signal by reaching to and activating some type of control. The verification that the response is complete usually occurs due to a combination of visual, audible, and tactile feedback. But what of the time period during which

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[103]Teichner, pp. 139-140.

the reaction takes place? It has often been suggested
that human response, control of precise hand and arm
motions, is analogous to "servo-response."[104] In other
words, human response involves the continuous comparison
of input and output with the error between the two used
as the basis for control. Arm motions, under this theo-
ry, are guided by a series of visual error measurements
between the actual hand position and the desired target;
changes in position result from an effort to reduce this
error to zero. It is further assumed that motions made
without visual feedback (i.e., blindfolded) require some
form of mental imagery as a substitute.

The value of this visual feedback was questioned in
an experiment by Taylor and Birmingham. They devised an
experiment to suddenly disrupt subjects' visual feedback
on a manual tracking task. In a first test subjects were
presented with a visual target which jumped quickly to
the left or right and could be brought back to center
with proper manipulation of a joystick. After several
successful maneuvers of the target suddenly the joystick
was disconnected and the target would no longer respond.
The experimenters observed that the subjects' now futile
response pattern did not change even though the target
could not be brought back to center. For a second test

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[104]Rube Chernikoff and Franklin V. Taylor, "Reaction
Time to Kinesthetic Stimulation Resulting From Sudden Arm
Displacement," Journal of Experimental Psychology, 43(1)
(January, 1952), 1.

the target was suddenly made to respond in the opposite direction. The subjects' initial response pattern did not change although a second opposite motion of the joystick was ultimately made.[105]

These studies led the experimenters to reject the servo hypothesis and conclude that visual feedback during a first reaction time period could not affect a response already in progress. Once a quick response was started it ran to completion; any adjustments were made during a later and distinct time period.[106]

Further analysis of the servo hypothesis was made by Chernikoff and Taylor.[107] They devised an experiment to test reaction time to kinesthetic stimulation (sudden motion of a body part). The kinesthetic stimulus was provided by attaching a subject's arm to a splint which was held by an electromagnet. The splinted arm was allowed to drop from a high starting point and the subject responded by either stopping the arm motion (one part of the experiment) or pressing a button with the opposite hand. In the first part of the experiment a subject's response was indicated by the onset of the change in acceleration as measured electronically.

The results indicated: "that kinesthetic reaction time is too long to permit continuous voluntary control

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[105]Chernikoff and Taylor, p. 1. [106]Ibid.

[107]Ibid., pp. 2-8.

of short duration hand and arm movements by information furnished through feedback."[108] The authors proposed a dual hypothesis of control where "volitional processes" issue orders for body movements and "nonvoluntary lower centers" execute the movements without further instruction.[109]

The human factors demonstrated in these two important experiments bear a direct relationship to human emergency response. In an industrial accident requiring a manual activation of an emergency stopping device, a human being's initial response will likely follow through to completion, whether or not the response is in error (i.e., if a stopping device is missed or not pushed hard enough). If an error is made another separate and distinct response will be required after feedback confirms the failure. If the accident involves an entanglement in a machine which could impart enough energy to throw the person off balance, the probability of missing the stopping device could greatly increase. A correct initial response would require instant human recognition of body position and acceleration with respect to the machine and an evaluation of where the body will be (with respect to the stopping device) when the response is initiated. In other words, the victim will, in effect, be required to hit a moving target; not because the stopping

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[108]Chernikoff and Taylor, p. 8.　　　[109]Ibid.

device is in motion, but rather, because his/her body is in motion with respect to the target. The difficulties in performing this feat while simultaneously coping with the fear and pain of entanglement could cause delay or ineffectual response if the stopping device is not in a familiar position, readily accessible, and easily activated.

Motor Reaction

One of the motor reactions commonly required in any human control operation is the movement of a limb (often an arm) as quickly as possible from one position in space to another.[110] The purpose of the motion, however, is more than just to accurately locate the limb in space; frequently the hand or foot is required to operate some type of mechanical control such as a knob, switch, pushbutton, or lever. Therefore, it is often desired to reach the control location both as quickly as possible and with a minimum of error and tremor.[111]

It has already been stated that positioning motions can be divided into primary and secondary movements. Primary or gross movements merely transport the limb to the

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[110]Judson S. Brown and Arthur T. Slater-Hammel, "Discrete Movements in the Horizontal Plane as a Function of Their Length and Direction," Journal of Experimental Psychology, 39 (1949), 84.

[111]Ibid.

general vicinity of required activity while secondary or
fine adjustments are necessary to compensate for any re-
sidual error. In an experiment by Brown and Slater-Hammel
these primary and secondary motions were studied.

For the experiment subjects were asked to move a
pointer, at the sound of a buzzer, as quickly and accu-
rately from one position in space to another along a
marked board. Through a reduction pulley arrangement,
motions of the pointer were transferred to a pen on a
strip recorder, thereby providing a continuous record of
pointer velocity and acceleration. The results showed
that in all records the onset of the stimulus was follow-
ed by a brief interval (the reaction time), then a rapid
acceleration and an apparent uniform period of high veloc-
ity before decelerating to zero; smooth changes were noted
between phases of increasing acceleration, relative uni-
form velocity, and deceleration. Most records showed
that the primary movement ended with the pointer either
short of or beyond the terminal line and secondary move-
ments resembled the familiar graphs of underdamped, crit-
ically damped, or overdamped oscillations.[112]

For the experiment the following important conclu-
sions were reached:

(1) The primary movement, which consists of a rapid

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[112]Brown and Slater-Hammel, pp. 84-95.

initial acceleration and a period of relatively
uniform velocity may on occasion terminate at
the exact desired point, but usually does not.

(2) A secondary corrective motion will usually be
required which may take on one of the typical
patterns of damped oscillation.

(3) Increases in length of movement were associated
with corresponding increases in duration of pri-
mary movement, velocity of movement, and varia-
bility in both time and speed.

(4) Secondary corrective movements remained relative-
ly constant for total movements within the range
of approximately 10 to 40 centimeters.

(5) Short excursion primary movements were usually
followed by long duration secondary move-
ments.[113]

The important concept of this experiment in relation
to emergency stop motions is that overshoot or undershoot
of a limb in motion will occur in the majority of cases.
If the emergency stopping device is not sufficiently
large to allow for error, the initial movement of the
hand (or foot) may miss the device causing a delay in
activation.

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[113]Brown and Slater-Hammel, pp. 94-95.

Training

The discussion of relevant human factors so far has focused on some of the aspects of actually reaching for a control device. This assumes that the operator knows where the control is and does not need to select the device from among other controls that may be located in the same vicinity. For example: the secretaries in the Warrick, Kibler, Topmiller experiment did not need to discriminate between controls. If the typewriter keys are excluded, there were no other devices to be confused with the stop button during emergency response. When the signal was given there was only one thing to do; no decision had to be made. Likewise, in the Johansson and Rumar experiment drivers did not need to discriminate. To an experienced driver reaching for the brake pedal is a normal event and the only mental process required during the experiment was an association of the audible signal with a need for a braking response.

However, in the industrial environment things may not be that easy; controls are becoming increasingly more complex. It is not uncommon to find seemingly incomprehensible arrays of lights, switches, and knobs on the same panel; lights flash different colors, knobs and switches control different functions, and alarms sometimes call for immediate attention. How then can an operator in an emergency quickly decide which control to use?

Quite often training is an important factor. As was shown in the experiment with secretaries, response time significantly decreased with practice over the six month period. The effect has also been noted in other studies of simple reaction time.[114] However, the simple reaction time does not require any complicated decision making process; Teichner proposed that any improvement observed with practice might be due, not to the effect of learning on the reaction itself, but on learning the proper preparatory interval.[115]

The choice reaction time would more nearly correspond to an industrial environment where operators need to decide when and what response is required depending on conditions observed. Many studies have found a significant correlation between the number of choices and the time needed to react.[116] It has been determined that decision reaction time varies as a direct function of the number of choices available.[117] The following data have been reported assuming each choice has an equal probability of occurrence:

[114]Teichner, p. 139.   [115]Ibid., pp. 139-140.

[116]Wargo, p. 225.

[117]Ernest J. McCormick and Mark S. Sanders, Human Factors in Engineering and Design (New York, 1982), p. 198.

Number of Choices	Reaction Time
1	0.20
2	0.35
3	0.40
4	0.45
5	0.50
6	0.55
7	0.60
8	0.60
9	0.65
10	0.65[118]

It is here that the effects of training have not been clearly established as most studies concerning choice re-action times allow subjects the advantage of practice runs before experimental data is taken. However, industrial engineers have long recognized the importance of practice in repetetive motions and the improvement in time of per-formance is firmly established.[119] In general, the reduc-tion in time is attributable to a general familiarity with the required movements and a reduction in the number of consecutive eye fixations required.[120] After practicing

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[118]McCormick and Sanders, p. 198.

[119]Ralph M. Barnes, Motion and Time Study Design and Measurement of Work (New York, 1980), pp. 197-201.

[120]Ibid.

a less defined visual picture of terminal location is needed during movement and grasping; a better coordination results. Learning curve theory has shown that the effects of practice generally produce a hyperbolic curve when plotting cumulative trials versus cumulative average time; also, it may take many hundreds of trials before an operator's learning curve begins to flatten out.[121] In an industrial environment requiring an emergency stop motion, faster response would be expected if the operator was familiar with the exact motions required. This would seem to indicate that the emergency stop motion should be utilized during routine stopping of equipment. This would be especially true if the emergency stopping response had to be discriminated from among a variety of other normal motions.

Discrimination

The ability to recognize the required control from among all other non-essential devices in the immediate vicinity is an important task within the context of a manual emergency stop. As was previously mentioned, practicing a movement has always shown improvements in speed of discrimination, coordination, reaction, and a general

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[121]Gavriel Salvendy, ed., Handbook of Industrial Engineering (New York, 1982), p. (4.4.10).

reduction in the amount of visual feedback required to
complete a response. Just as a trained automobile driver
can learn to reach instinctively for required controls,
so too can the industrial operator. However, with the
complexity of modern equipment it cannot be assumed that
all operators have had the necessary training or could
instantaneously produce an emergency stop motion when
required to do so. Therefore, for those persons not ca-
pable of instinctive response, the ability to discriminate
becomes very important.

Color coding has always been an important factor in
proper discrimination of controls. Historically, the
emergency stop control has been colored bright red to be
consistent with human expectations from other coding
schemes using red as the symbol for danger or stop. Red
as significant to danger is clearly established and is
derived from blood; in war, red flags as symbols of com-
bat have been used for many centuries.[122] Red has also
been found superior for distant discrimination even though
its apparent brightness shifts with low illumination.[123]

Color as a coding dimension for displays has been an
effective means for reducing search time.[124]

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[122]Arnold Whittick, Symbols, Signs and Their Meaning
and Uses in Design (Newton, Massachusetts, 1971), p. 301.

[123]Mari Riess Jones, "Color Coding," Human Factors,
4 (1962), 363.

[124]Ibid. pp. 358, 364.

In an experiment by Hitt et al subjects were asked to
search numerals, letters, geometric shapes, colors, and
configurations for five types of tasks: identification,
counting, comparing, locating, and verification. Both
color and numeric codes were shown to be superior in the
locate task.[125] In a second experiment, the same group
found that color coded targets on maps were located and
counted significantly faster than when numerals and en-
closed shapes were used as a coding dimension.[126] In an
experiment by Shontz et al with color coding for informa-
tion location (again using maps) it was found that sub-
jects were able to locate checkpoints significantly faster
than if non-coded maps were used.[127]

Although color coding has proven effective in pro-
viding ease of discrimination among targets, it has also
been found that the nature and number of coded but non-
searched objects in a display (clutter) can seriously de-
grade the response time performance.[128] A search situa-
tion invariably involves more than one stimulus in a
field of view with only one target of superior importance.
Furthermore, the same targets may become unimportant in
succeeding trials. Therefore, any coding scheme that in-

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[125]Jones, p. 359.   [126]Ibid.

[127]William D. Shontz, Gerals A. Trumm, and Leon G.
Williams, "Color Coding for Information Location," Human
Factors, 13(3) (June, 1971),237-246.

[128]Jones, pp. 359-360.

creases discriminability may also increase the distracting effect of non-targets if it is applied equally to all objects in the display. For example: an industrial control panel may consist of five pushbuttons with five respective warning lights. If all objects on the panel are the same size and merely differ in color, then the nine non-searched objects, all brightly colored and distinct, could increase confusion during an emergency response. A panicked operator might try inadvertently to push a warning light rather than its corresponding pushbutton.

In studying this effect, Smith found that when targets differed both in size and contrast, median search time was significantly shortened than for contrast or size differences alone.[129] Weitz reported a similar observation; he found that the response time to control levers was faster if they differed in both color and shape than if they differed only in color or shape.[130] Eriksen and Hake expanded the experiment to include brightness so their targets differed in three dimensions. The results showed that multidimensional stimuli were much easier to discriminate than when only single dimensional differences were used.[131]

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[129]Jones, p. 360.

[130]Charles W. Eriksen and Harold W. Hake, "Multidimensional Stimulus Differences and Accuracy of Discrimination," Journal of Experimental Psychology, 50(3), 153.

[131]Ibid., p. 159.

Geometric forms have also been studied in regard to this question of discriminability. Sleight studied the relative discriminability of geometric forms when they constituted a complex panorama with which subjects had to deal. Both efficiency in terms of sorting time and the relative attention-getting value were considered. In all, six each of twenty-one different geometric figures were used (see figure 3-1) for a total of 126 objects.[132] The task of the experiment required subjects to sort each set of these forms and place them in compartments on a display board as quickly and accurately as possible. All geometric shapes were sized to be the largest that would fit into a one inch circle; areas were therefore not the same. The following results were obtained:

    (1) Discriminability was approximately ten times faster for the first ranking figure compared with the last as measured by sorting time.

    (2) On the basis of significant differences it was possible to identify four separate groups of geometric forms each of which was equally discriminable. The best group consisted of: swastika, circle, crescent, airplane, cross,

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[132]Robert B. Sleight, "The Relative Discriminability of Several Geometric Forms," _Journal of Experimental Psychology_, 43(4) (April, 1952), 325-326.

Experimental Geometric Forms
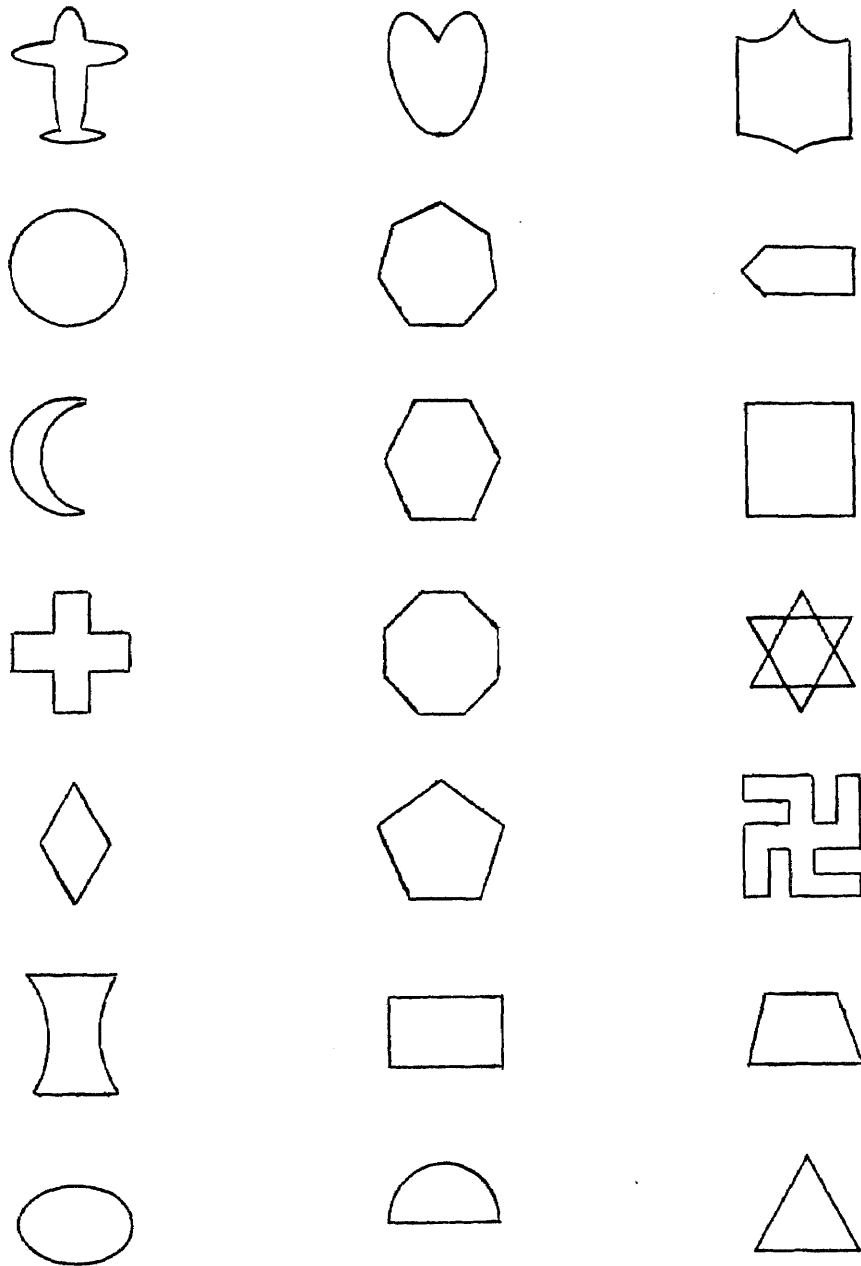
Source: Robert B. Sleight, "The Relative Discrimin-
ability of Several Geometric Forms," p. 325.

Figure 3-1

and star.

(3) A high positive correlation was found between sorting time and ranking based on subjects' order of selection (attention-getting value).[133]

In general, the results of these studies seem to indicate that an emergency stop device will be more easily and quickly discriminated from other controls on a panel if it differs in color, size, and shape. Furthermore, the vicinity of the emergency stopping device should not be cluttered with other controls which might reduce discriminability under emergency conditions. Evidence from human experimentation suggests that relatively unimportant or seldomly used controls on the same panel should receive a lower level of coding, thereby reducing distraction during emergency response. Since the circle was shown to be one of the most discriminable shapes in Sleight's experiment, the total evidence of these studies suggests that a large, red, round, pushbutton on a panel of smaller, non-red objects could be superior in terms of ease of discrimination during emergency response.

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[133]Sleight, p. 328.

Summary

The preceding discussion of human factors has focused on the effects normal human tendencies may have on an emergency response. A life time of observation might induce an engineer to surmise that some people would be naturally slow or error prone in producing an emergency response and not much could be done to improve their performance. Although this might seem to be confirmed when experimental reaction time data show skewing of response times, the truth is, much can be done during the design of equipment to compensate for these slower individuals if normal human tendencies are studied and the principles applied. According to Wargo, a human being "... is placed in a system's control loop when any one or any combination of, ... , sensing, pattern recognition, decision making, and planning ability is unequaled by existing electro-mechanical devices of comparable cost, weight, and size."[134] Therefore, if positive human traits are to be exploited, then an allowance must be made for error, especially in those areas where human judgement or response might prove faulty. In other words, when utilizing human beings as control operators the good must be accepted with the bad and equipment designed accordingly.

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[134]Wargo, p. 221.

Therefore, with these thoughts in mind, the following major chapter conclusions are summarized:

(1) Almost every disaster has some critical time period during which a response can minimize or avert damage.

(2) Every human response consists of various processes including: receptor stimulation, recognition, decision, neural conduction, muscle activation, etc. These processes take time.

(3) Any human response consists of a reaction time and a movement time which are distinct and separable quantities.

(4) Expectation can dramatically influence a person's state of readiness and can seriously affect response time.

(5) The distribution of human emergency response times during periods of low expectancy could be severely skewed due to those persons who do not immediately know what to do.

(6) Consistent improvements in performance are generally seen when human beings practice response motions.

(7) Humans are often startled by rapid changes in stimulus intensity and this may or may not improve response time performance due to extraneous muscle tensions developed.

(8) Repeated loud sounds can increase muscular tension levels in humans for indefinite time periods. This could prevent an immediate recognition of an emergency thereby slowing or preventing emergency response.

(9) Visual feedback does not seem to control responses already in progress. If an error is made, a second and distinct reaction time will likely be needed to make any corrections.

(10) Kinesthetic feedback appears to take too long to allow continuous control of short duration limb movements. It appears that volitional processes issue orders for body movements and nonvoluntary processes execute these movements without further instruction.

(11) Motor reaction of a limb will almost always consist of a gross movement and an oscillatory secondary movement.

(12) An industrial control response would more nearly correspond to a choice reaction time. Choice reactions have been shown to require dramatic increases in decision time with total number of choices available.

(13) Under choice reaction time conditions effects of practice could be expected to improve response time and accuracy.

(14) Color coding has been shown to be superior in

improving discriminability of objects in a display if all objects are not coded equaly.

(15) Multidimensional coding has proven to be superior to single dimensional coding in improving discrimination.

The following recommendations are made about design and placement of emergency stopping devices and machine design to be consistent with human expectations and established ergonomic principles.

(1) Provide audible warnings of impending system malfunctions requiring manual emergency stops whenever practical.

(2) Allow operators to practice the emergency stop motions regularly by utilizing these motions for routine stopping of equipment.

(3) Utilize the minimum power necessary, including mechanical power and electrical voltage to produce the desired result.

(4) Minimize audible vibration of equipment.

(5) Locate the emergency stopping device in a familiar position and make it easily activated and readily accessible.

(6) Standardize the location of emergency stop controls on different pieces of equipment.

(7) Make the emergency stop device sufficiently

large to minimize misses when undershoot or
overshoot of the response limb occurs.

(8) Color code the emergency stop device red.
Do not use red coding on any other control.

(9) Make the emergency stop device round when-
ever practical.

(10) Make the emergency stop device larger than
other controls on a panel.

(11) Segregate the emergency stop device from
other controls on a panel.

CHAPTER IV

THE EXPERIMENTAL METHOD

Introduction

One major difficulty encountered in any experiment
which would attempt to analyze human responses to emer-
gencies is how to accurately reproduce the desired con-
dition in a laboratory setting. For this study, the
problem of simulating the industrial accident requiring
manual activation of an emergency stopping device was
considered.

It was hoped that the methods used by previous
experimenters would suggest some practical way to approach
this problem. However, the nature of the task and the
seriousness of the event under study have forced experi-
menters to remain far short of generating actual emergen-
cies. Situations that would approach the severity of a
runaway industrial machine, a human arm caught in a gear,
or a major electrical short-circuit cannot be safely con-
trolled or reproduced; therefore, they cannot be system-
atically studied without a serious risk of injury to
subjects and experimenters. Because of the dangers and
complexities there has been a necessary reluctance to
study this very important problem. Furthermore, the data
that are collected are often very specific and do not

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apply to varied industrial situations.

Many factors in the environment can contribute to
the overall response time of an individual during an
accident. How fast can a human being respond to an
emergency stimulus and take the proper corrective steps
is a very practical and frequently asked question. The
truth is, we can't really say for sure because of the
effects of unforseeable variables. Has the operator
been forwarned to an impending crisis or has the situation
gone critical unexpectedly? Has the operator been ex-
posed to similar emergencies before? Are there extraneous
stimuli present that could impede recognition of an emer-
gency signal? What is the operator's level of motivation
and is he/she tired or distracted? These and other human
factors can be expected to affect the person's response
time to an industrial accident. Furthermore, with indus-
trial operators often required to perform many duties
simultaneously, he/she might not even be physically within
reach of the emergency stopping device; thus the problem
is often seriously compounded.

Therefore, it is the purpose of this experiment to
test human response times to actuate different types of
emergency stopping devices (pushbuttons) that are commonly
used on industrial equipment. Statistically significant
differences in response times and miss frequencies are
related to design and a modification of the standard
mushroom style button is made in an effort to reduce miss

frequency.

Subjects

Thirty-one subjects with ages ranging from 16 to 61 years participated in the experiment. The mean age was 33.2 years with a standard deviation of 13.8 years. Sixteen subjects were male, fifteen were female and none were considered by the experimenter to have any qualifications or training that would make their response times to emergency stopping devices non-representative of the population in general. Some exceedingly fast and some exceedingly slow subjects' individual and average response times were noted among those sampled. These were attributed to normal human variability, differences in motivation (subjects' attitudes and recognition of the importance of an emergency response), and deliberateness (subjects' attempts to perform accurately by utilizing conscious deliberate control of arm motions). It was assumed that all data collected represented normal variability within the general population and no attempts were made to eliminate any subject's average or individual response times.

Design

The experimental design consisted of two different emergency stop pushbuttons that were mounted on individual

consoles. The first console contained a standard 7/8 inch collar protected pushbutton that had been modified to allow collar removal. See figures 4-1 and 4-2. The second console contained a standard 7/8 inch collar protected pushbutton that was fitted with a standard 3 inch diameter mushroom head. See figures 4-3 and 4-4. The mushroom head was allowed to rock within its mount thereby allowing an emergency stop activation to occur by either rocking the button or pressing straight on. An alternate 3 inch diameter experimental mushroom head was designed by the experimenter and built to accept an identical set of mounting hardware. See figures 4-4 and 4-5.

The experiment was divided into two phases. During phase I each subject was tested for response times to four different arrangements. These were called tests A, B, C, and D. During phase II subjects were tested on four different arrangements designated tests E, F, G, and H. Phase I and phase II were completed for each subject at a different sitting and all subjects performed phase I testing before proceeding to phase II. Variability was from one to six weeks between phases.

For each test arrangement (A - H) the subject was seated in front of a console and was directed to actuate the device upon hearing an audible signal. After several trial runs to familiarize the subject with each arrangement the experiment began and each emergency stop arrangement was activated twenty times in response to randomly timed
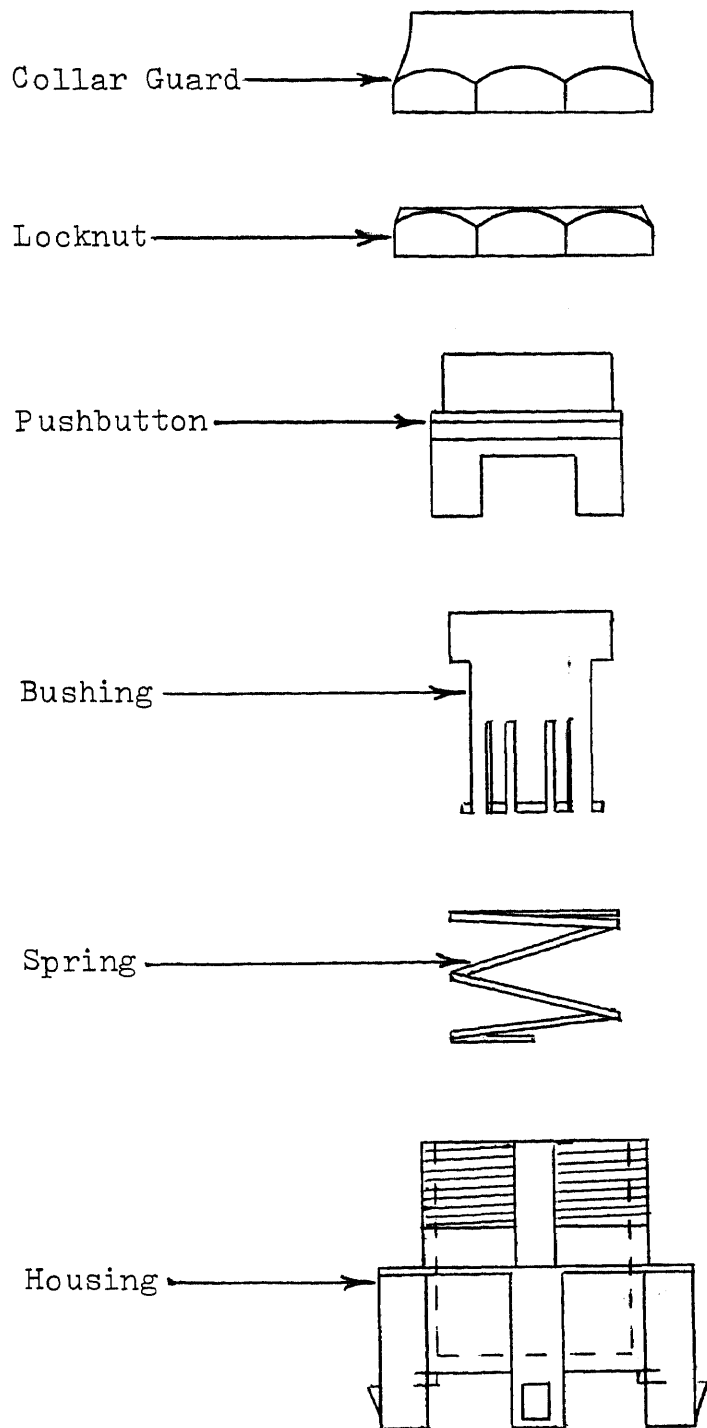
Standard Pushbutton - Exploded View

Collar Guard

Locknut

Pushbutton

Bushing

Spring

Housing

Figure 4-1

Standard 7/8 Inch Collar Protected Pushbutton With Modification

Pushbutton

Collar Guard

Locknut

Figure 4-2

Mushroom Head

Spring

Retainer

Washer

Pushbutton

Spring

Housing
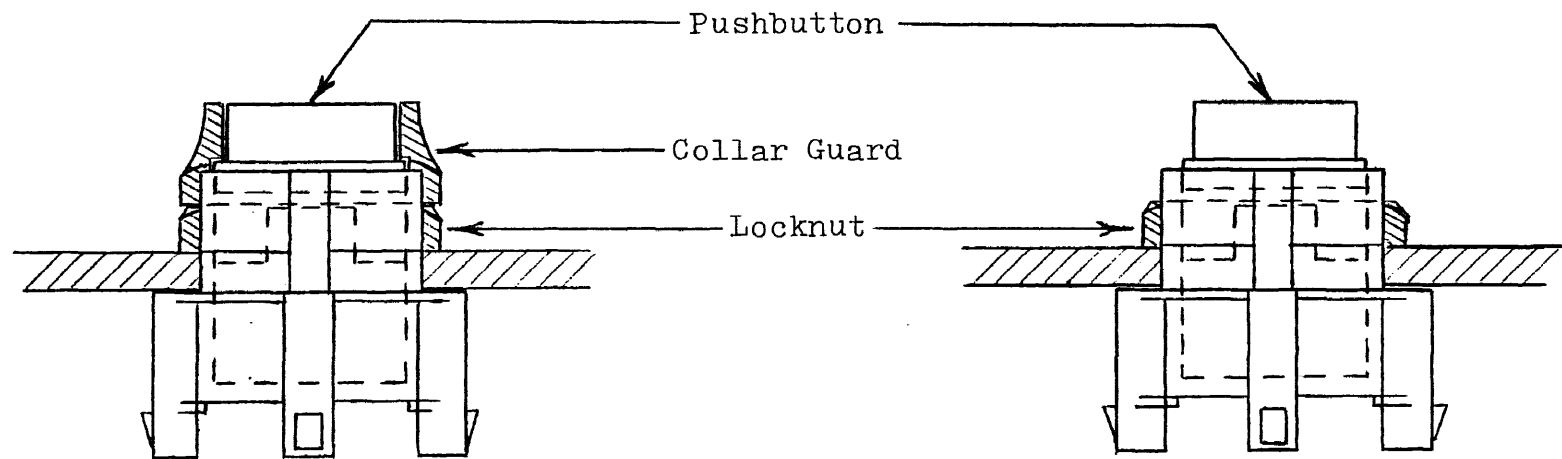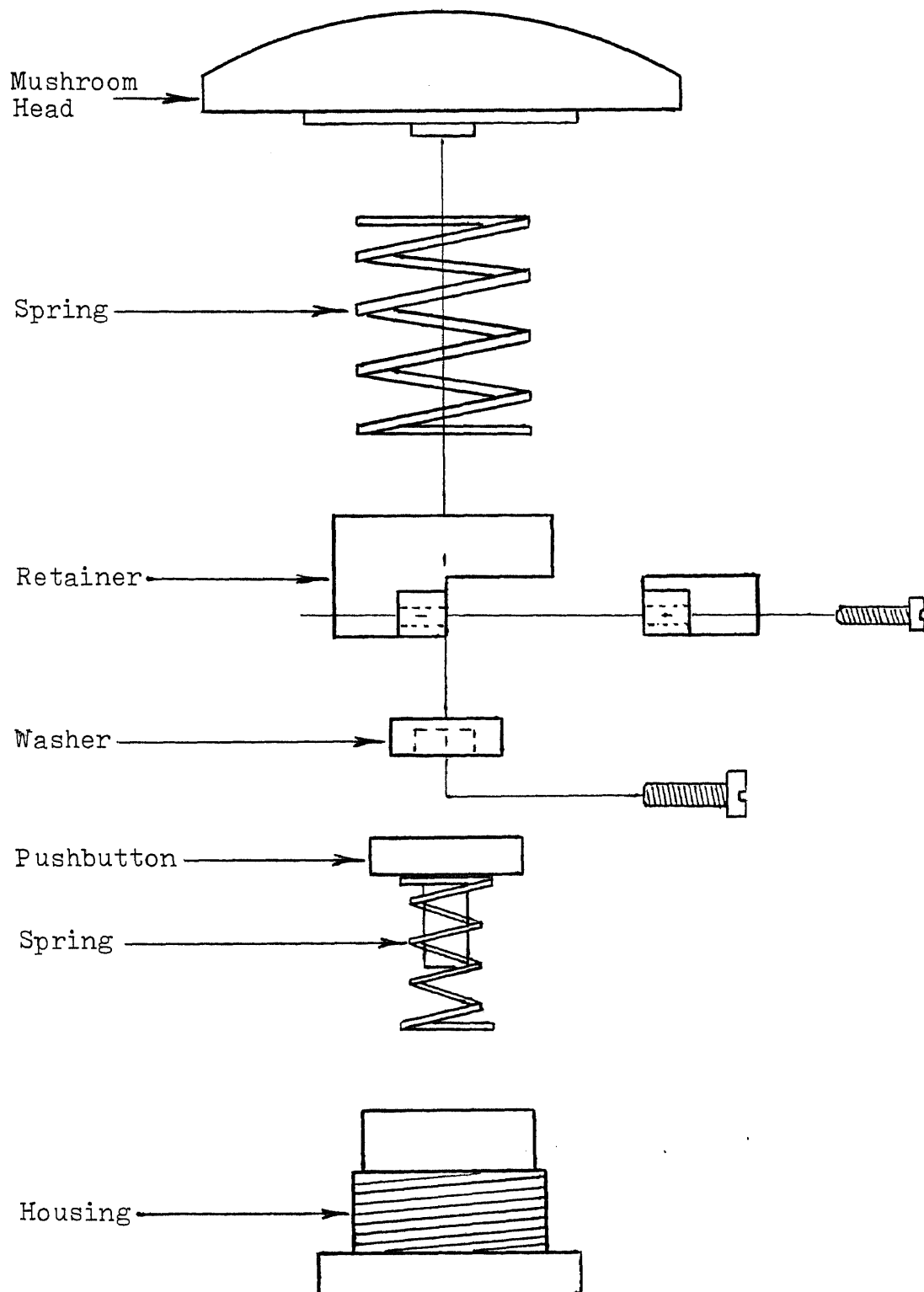
Figure 4-3

Standard 3 Inch Diameter Mushroom Head Pushbutton and Experimental Design

Figure 4-4

Alternate
Mushroom →
Head

Spring →

Retainer →

Washer →

Pushbutton →

Spring →

Housing →
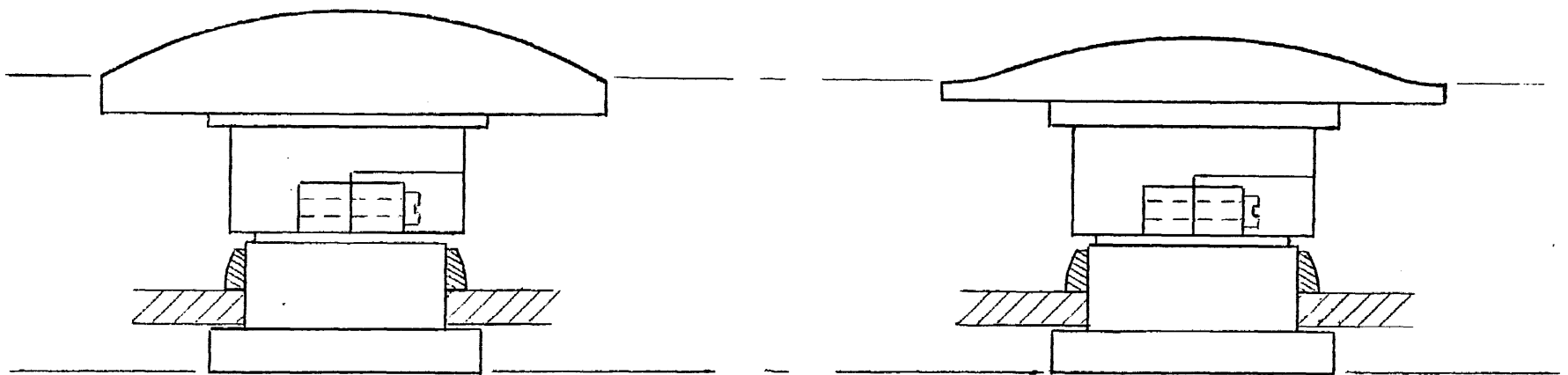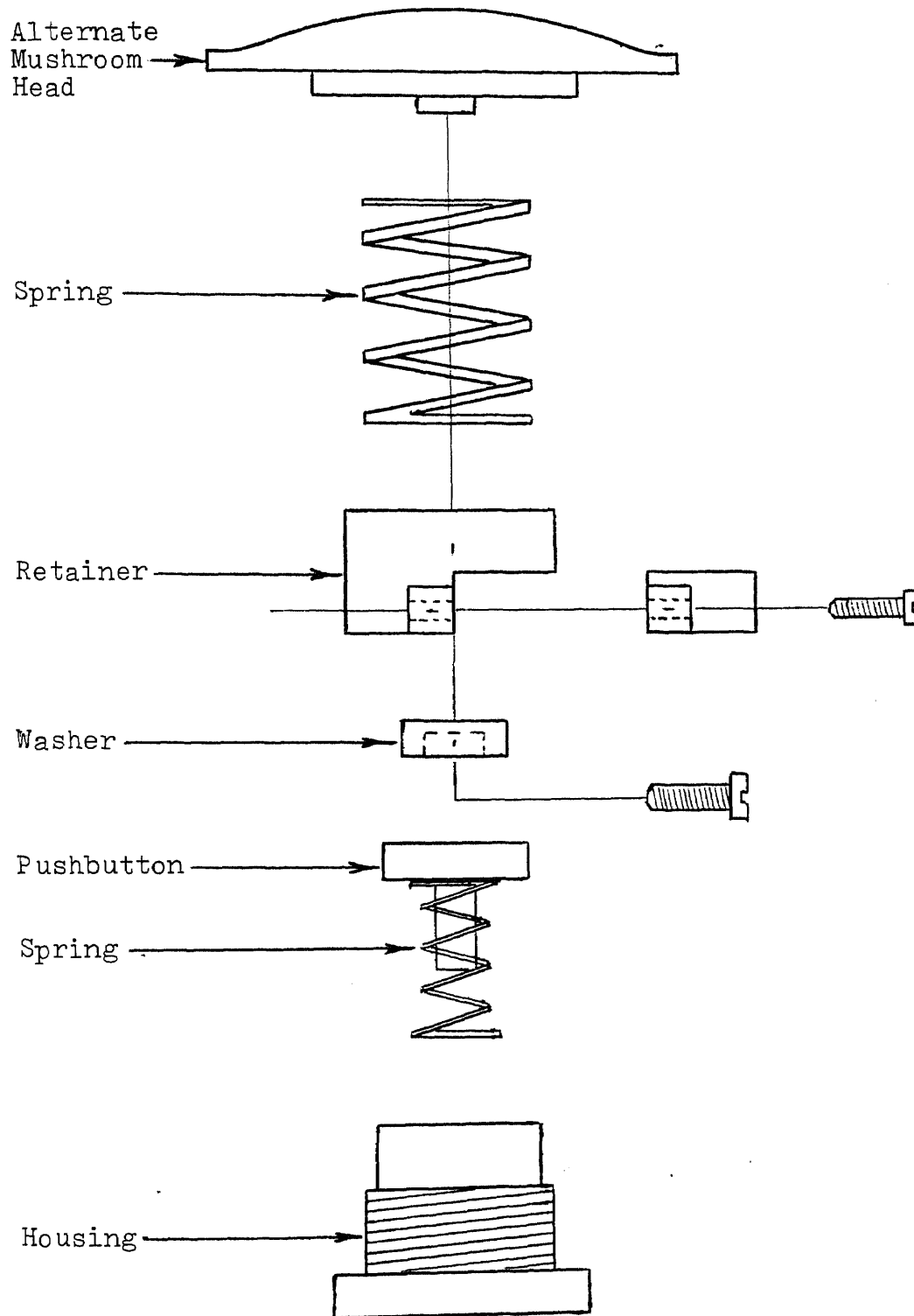
Figure 4-5

emergency signals.

Subjects' attention during the experiment was diverted from the emergency stopping task by having an assistant ask them questions from a popular game of trivia. Therefore, in addition to staying alert for the alarm signal, each subject was required to continuously answer a stream of questions that were completely irrelevant to the immediate experimental task. In this way a diversity of mental activity was obtained and concentration on response time was interrupted.

Randomness was achieved by varying the number of questions asked between trials. A random number table was used to generate lists of random numbers between 0 and 4 and these lists were used to determine the number of questions to be asked between trials. Initiation of the audible signal occurred during the asking or answering of the last question according to the experimenter's discretion. Since the experimental assistant was trained not to rush the subject with a flurry of questions, quite often a discussion about some particular answer would develop, thereby increasing normal variability between questions. Although intertrial elapsed time was not recorded, no trials were observed to take longer than three minutes to complete.

Ordering of arrangements presented was randomized during each phase of the experiment to reduce the effects of practice and fatigue on the results. There are twenty-

four possible combinations of four arrangements and each
of the first twenty-four subjects was given a different
combination. Combinations were chosen at random for sub-
jects twenty-five and up.

Apparatus

The materials used in the experiment were red emer-
gency stop pushbuttons commonly used on industrial devices.
The buttons were arranged on two identical consoles as
shown in figures 4-6 and 4-7. For phase I the four ex-
perimental arrangements consisted of:

Test A - 7/8 inch collar protected button

Test B - 7/8 inch button with collar removed

Test C - 3 inch standard mushroom button

Test D - 3 inch standard mushroom button
         (subjects were instructed to use
         their non-favored hand for response)

Spring tension and travel distance were adjusted to
be equal on both consoles. Activation force required
was 3 pounds straight on and activation distance was 1/8
inch. These parameters were measured with a Dillon 25
pound capacity, 1/4 pound division compression force gauge,
a vernier caliper, and an electronic ohm-meter to verify
electrical switch contact.

For phase II of the experiment subjects were fitted

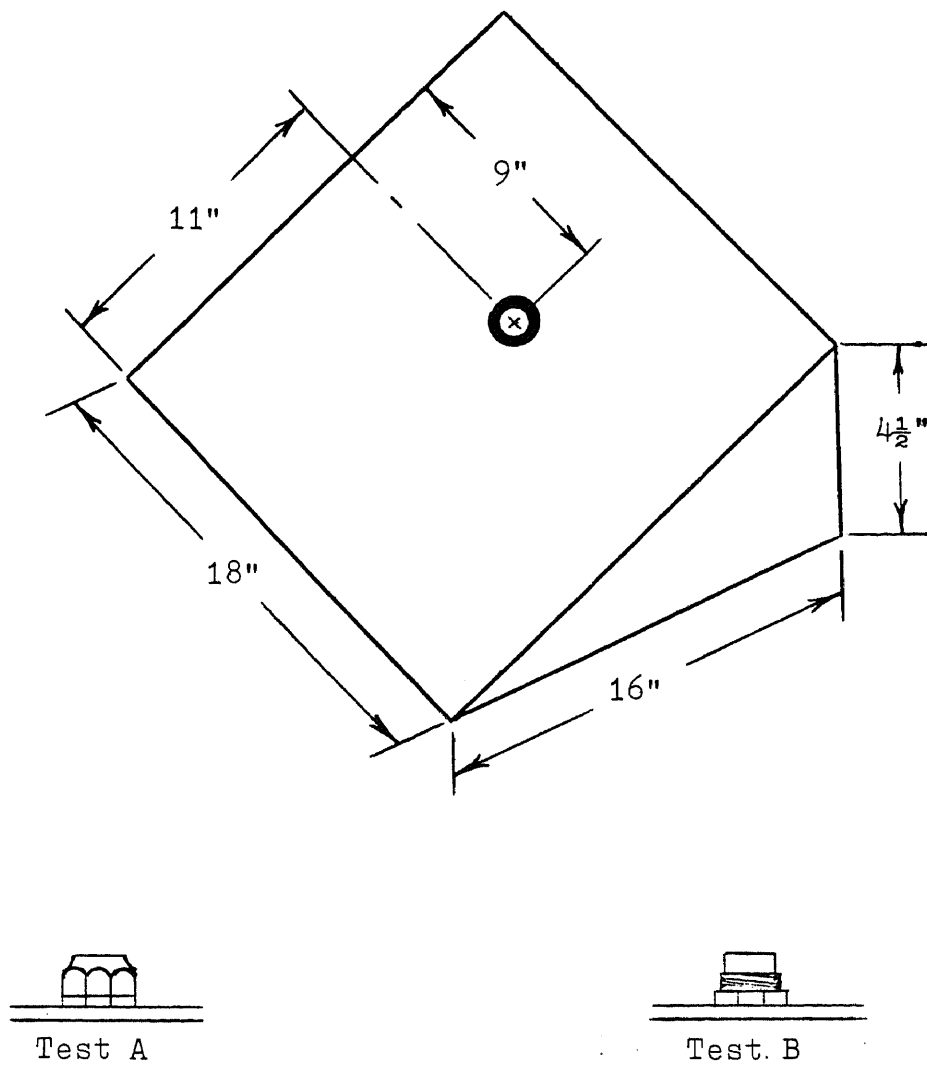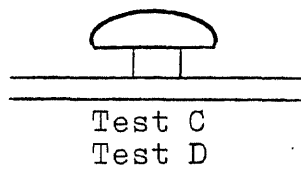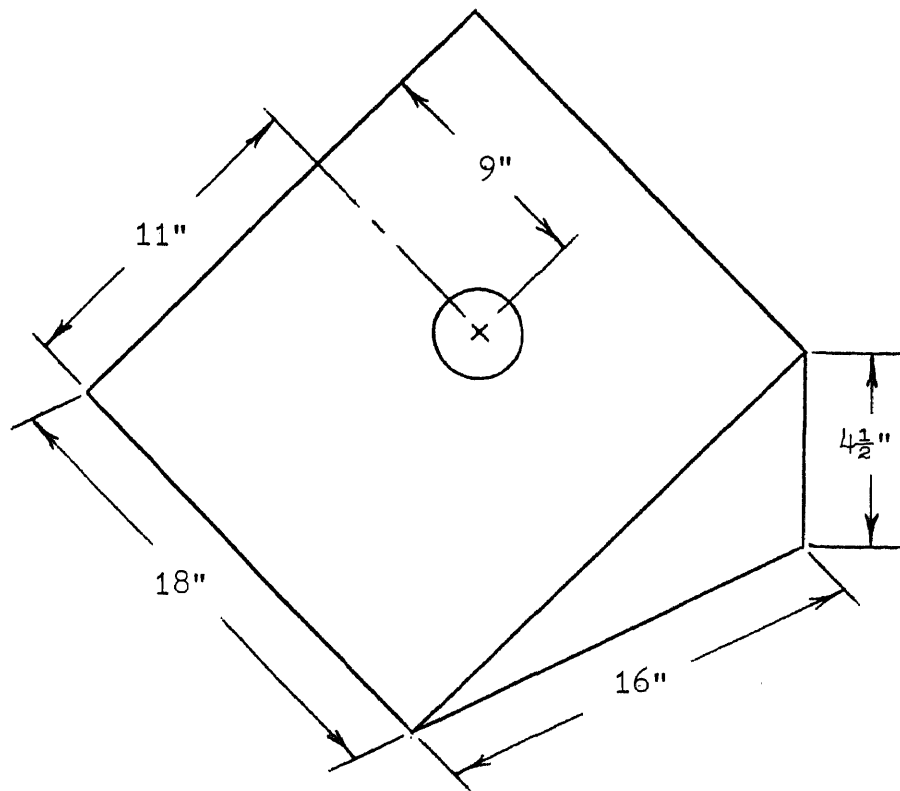First Console

Test A

Test B

Figure 4-6

Second Console

Figure 4-7

with a surgeon's style rubber glove on their favored hand.
The glove and the emergency stop pushbutton under test
were thoroughly sprayed with silicone lubricant before
each test was started. Pushbutton surfaces used for
phase II testing had been previously prepared by sanding
to bare metal with 400 grit paper and painting with four
coats of glossy red spray enamel. Paint was baked dry
and buttons were examined to ensure identical surfaces.
Spring tension was adjusted within each mounting mechanism
to increase required activation force to 7-1/2 pounds.
Activation distance remained unchanged. The four experi-
mental arrangements consisted of:

        Test E - 3 inch standard mushroom button

        Test F - 3 inch experimental button

        Test G - 3 inch standard mushroom button
                 (Subjects were blindfolded)

        Test H - 3 inch experimental button
                 (Subjects were blindfolded)

The tester's console for activation of the audible
alarm and timer is shown in figure 4-8. The wiring of
this console and its interface with the experimental con-
soles and timer is shown in figure 4-9. The timer used
was a Lafayette Instrument Company model 58007 with a
precision of 0.01 second. The alarm was a Floyd Bell
Associates continuous tone device.

An overall block diagram of how the experiment was
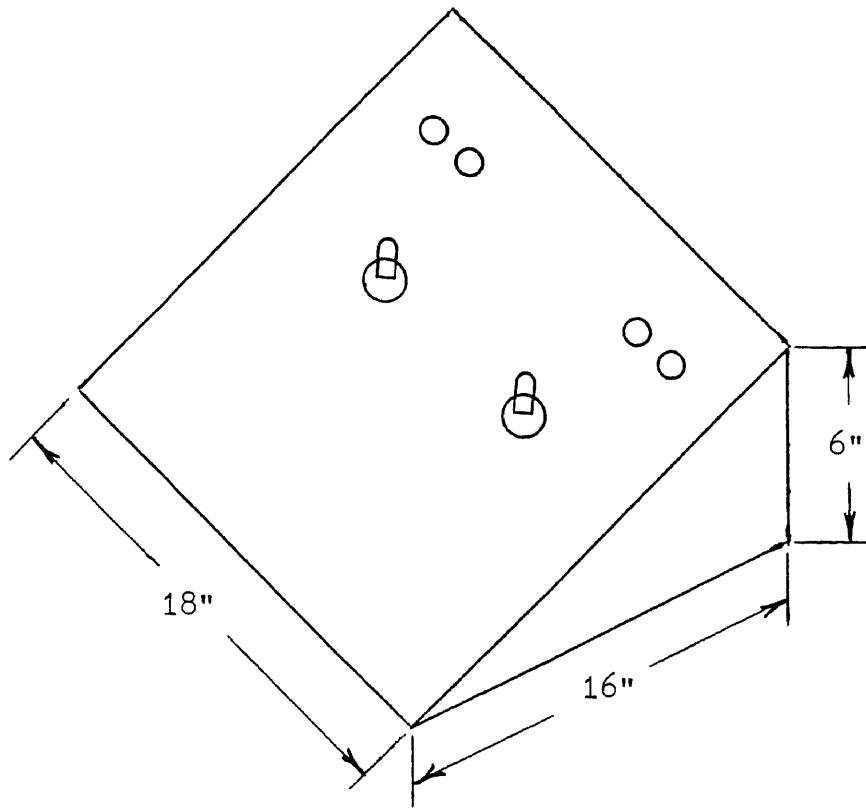
Tester's Console

Figure 4-8

Wiring Diagrams for Normally Open

and Normally Closed Pushbuttons
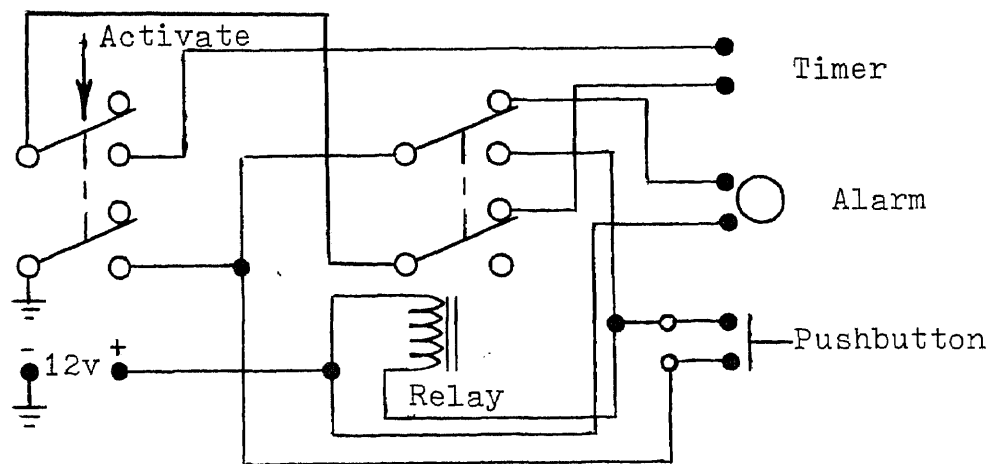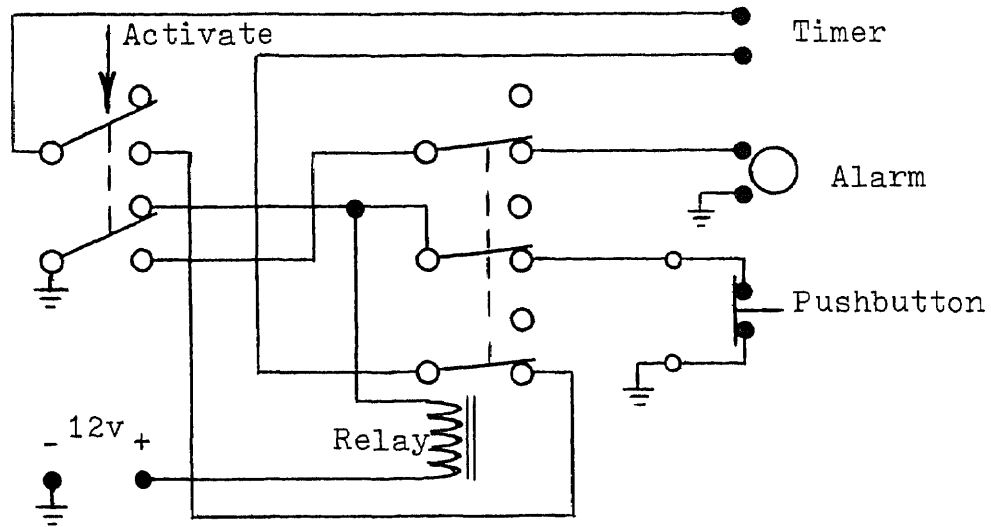
Figure 4-9

conducted is shown in figure 4-10. The design of the consoles resulted in both the audible alarm and timer being activated by the experimenter through the operation of one switch. Likewise, both the alarm and timer were stopped simultaneously by activation of the pushbutton on the subject's console.

Procedure

Each subject was seated in front of a pushbutton console and was told that he/she was in control of an industrial machine. This machine could be any type of device he/she could imagine, such as: an industrial robot, automatic arc-welder assembling automobiles, a nuclear reactor, a conveyor, hydraulic press, etc. Each subject was then given the following instructions:

(1) Please face the console with your hands placed on the table to the sides of the console. You may not rest them directly on the console.

(2) You will be asked questions concerning everyday subjects which have been taken from a popular trivia game.

(3) At random times during the questioning you will hear an emergency signal which sounds like this: (experimenter momentarily activates the alarm).

(4) Upon hearing the alarm you are to press the

Block Diagram
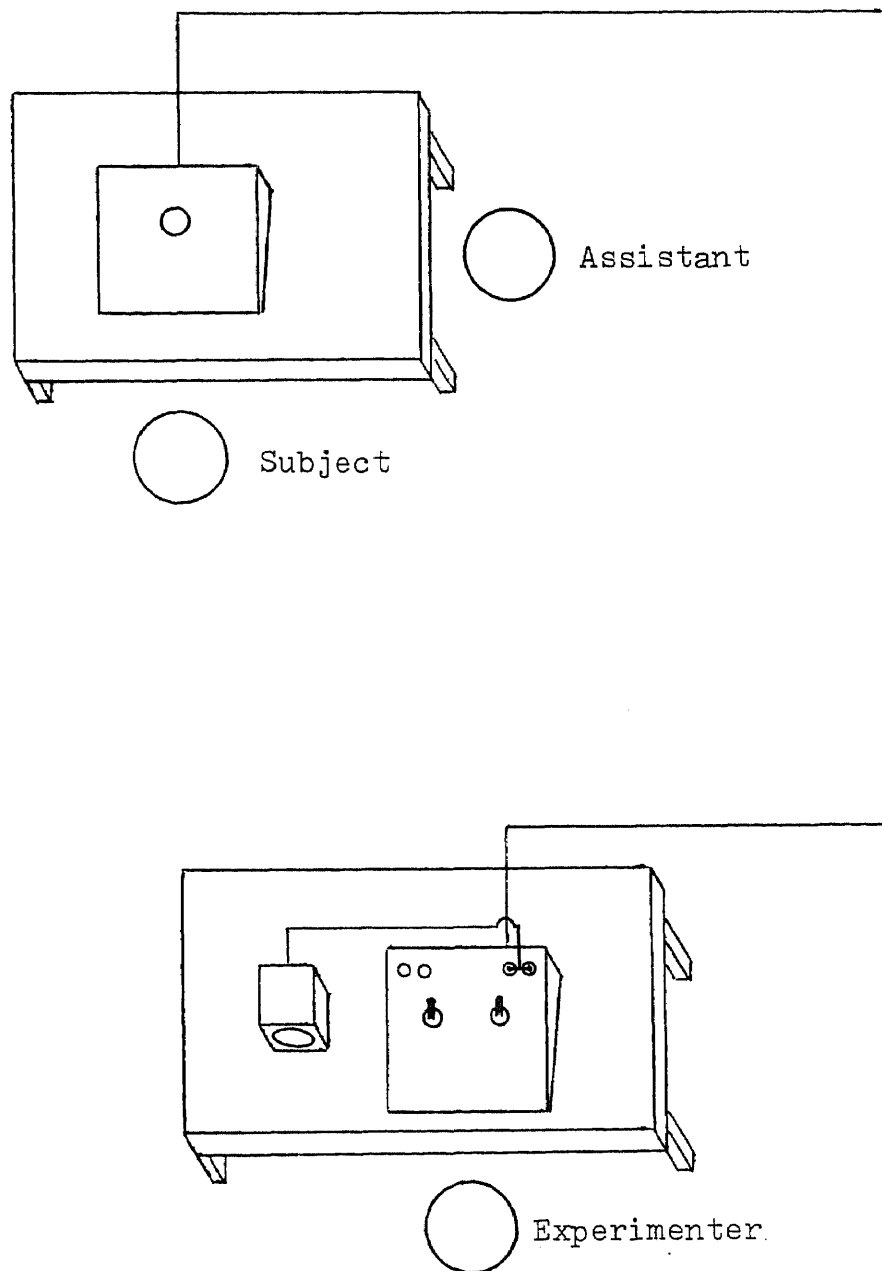
Figure 4-10

emergency stop button as quickly as you can
to silence the alarm.

(5) Please activate the device (experimenter
activates the alarm, subject presses the
button).

(6) If you miss or do not press the button hard
enough and the alarm continues, please press
it again until the alarm stops.

(7) Do you have any questions?

Subjects were allowed to ask questions about the
experiment and practice several activations of the emer-
gency stopping device. When they were ready the testing
began. After twenty trials were completed on the first
arrangement and response times recorded on the data sheet
the experimenter replaced the first arrangement with the
second. Again, the subject was allowed to make several
practice activations of the device and when he/she was
ready the testing began. Third and fourth arrangements
were done identically.

The experimental assistant began asking questions
each time that the subject indicated he/she was ready to
begin a test. Using a list of random numbers the experi-
menter counted questions and activated the alarm and
timer. Upon proper activation of the emergency stopping
device by the subject the alarm and timer were stopped.
The experimenter then recorded each response time in the

appropriate column on the data sheet and reset the timer for the next trial. During each trial the experimenter carefully observed the response of the subject and noted any deviations on the data sheet. If the subject was distracted and failed to respond immediately to the alarm, a notation of "distracted" was recorded next to the response time. If the subject needed two or more tries to silence the alarm then a "miss" was recorded and if the subject experienced visible manual difficulty but only needed one try then the notation "slipped" was recorded. The experimenter recorded a deviation only when mentally certain that one had actually occurred. When any uncertainty existed the trial was considered normal. All response times, regardless of recorded deviations, were recorded as registered and every response was considered a legitimate trial.

The conditions in the room where the experiment was conducted simulated an ideal industrial environment. It was well lighted and subjects faced their control consoles. The experimental assistant sat directly alongside the subject and the experimenter sat behind the subject's field of view.

Statistical Analysis

For each phase of the experiment subjects were asked to respond to audible signals by immediately pressing an

emergency stopping device, thereby deactivating an armed
electrical circuit. The total elapsed time for the system
response (including the human element) was recorded as the
response time and sets of twenty trials for each subject
were used to compute an average. Subjects activated dif-
ferent devices and/or responded under different experi-
mental conditions depending on the testing arrangement.
For example: by comparing tests A and B it can be seen
that both tests utilized the same 7/8 inch pushbutton
device but the mechanical conditions were changed; namely,
the protective collar was removed for the second arrange-
ment. For another pair of tests, subjects activated dif-
ferent devices but mechanical conditions were left un-
changed. For example: by comparing tests B and C it can
be seen that there was a change from a 7/8 inch unguarded
pushbutton to a 3 inch unguarded mushroom style pushbutton.

It is assumed that the protective collar used on the
7/8 inch pushbutton was included in the design to prevent
accidental activations (bumping); but one of the disadvan-
tages to a guarded pushbutton is the requirement for an
operator to use a single finger for activation. The
blind frightened swipe of a palm during an extreme emer-
gency might not be reliably expected to activate this type
of device. In other words, it might be hypothesized that
a guarded pushbutton would, on the average, take longer
to activate thereby increasing the severity of damage or
human trauma in an accident.

The question of interest for the comparison of the guarded and unguarded pushbutton is: can the observed difference in average human response time be attributed to chance or is it statistically significant? Likewise, for the other testing arrangements of this experiment the purpose of the comparisons is to see if observed differences in response times can be considered statistically significant.

Standard statistical methods of testing sample means for significant differences usually require that independent samples be taken. For this experiment that would mean eight different sets of human subjects would be needed, one for each experimental arrangement. However, for identical samples (i.e., humans performing an identical number of trials under different testing arrangements) paired statistical comparisons can be made. The paired situation alludes to the common "before and after" type of test. Therefore, the following paired comparisons of response time data are made for this experiment:

(1) A - B; 7/8 inch pushbutton, guarded vs. unguarded

(2) B - C; 7/8 inch standard button vs. 3 inch mushroom head, both unguarded

(3) C - D; mushroom button, favored vs. non-favored hand

(4) E - F; Mushroom vs. experimental mushroom head

(5) G - H; mushroom vs. experimental mushroom head

Statistical Procedure for Test Pair: A - B[135]

(1) For n subjects over twenty trials the average

response times R_{iA} and R_{iB} are computed.

$i = (1, 2, \ldots, n)$

(2) Paired differences are computed.

$D_i = R_{iA} - R_{iB}$

(3) Deviations $d_i = (D_i - \bar{D})$ are assumed normally

and independently distributed with population

mean equal to zero.

(4) $S_D^2 = \underset{i=1 \text{ to } n}{\text{Summation}} (D_i - \bar{D})^2/(n - 1)$

(5) $S_{\bar{D}} = (S_D^2/n)^{\frac{1}{2}}$

(6) $t = D/S_{\bar{D}}$ d.f. $= n - 1$

(7) For the paired data:

$H_0: \mu_D = 0$

$H_A: \mu_D \neq 0$

the null hypothesis is tested against the

alternative hypothesis using the t statistic.

Analysis of Miss Frequencies

When studying human response to different arrange-
ments of emergency stopping devices, the question might
occur: could a particular arrangement increase the like-

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[135]George W. Snedecor and William G. Cochran,
Statistical Methods (Ames, Iowa, 1967), pp. 92-97.

lihood of a missed response? In other words, could the design of the device occasionally prevent a human operator from completing an emergency stop? For example: in comparing the guarded and unguarded buttons it might be hypothesized that the guard increases the probability that an operator could fail to activate the device on the first attempt. If so, the miss would increase the delay in stopping a machine and could increase the severity of damage or human trauma in an accident.

The question of interest is: can the observed differences in frequencies of miss response for this experiment be attributed to chance or are they statistically significant? Therefore, the following paired comparisons of miss frequency data are made for this experiment:

(1) A - B; 7/8 inch pushbutton, guarded vs. unguarded

(2) B - C; 7/8 inch standard button vs. 3 inch mushroom head, both unguarded

(3) E - F; mushroom vs. experimental mushroom head

(4) G - H; mushroom vs. experimental mushroom head

The statistical procedure used in comparing miss frequencies is identical to that used for response times. The variable M_i is used in place of the average response time R_i in the previous example and the same procedure is used to test null and alternative hypotheses. For all comparisons made in this experiment a null hypothesis is rejected only after the computed t value indicates the

95% level of statistical significance is exceeded.

In counting missed/slipped trials during the experiment it was realized that a rather subjective judgement by the experimenter was required each time a miss/slip was recorded. Although the visible and audible effects of a miss/slip were often very evident, it was concluded that errors could be made in judgement. Furthermore, it was determined that the most detrimental effect of missing or slipping was a lengthened elapsed time of response. If the subject actually missed or slipped on the response but then recovered with sufficient speed to prevent an excessive elapsed time then there would be no detrimental effect. Trials such as these should not be considered a deviation. Therefore, the following procedure was used to eliminate these non-excessive deviations:

(1) Each subject's response times for each test arrangement were used to compute a mean ($\bar{x}$) and standard deviation (s) for the twenty trials. Missed/slipped trials were not included.

(2) The value $\bar{x}$ + 2s was then compared to the response time of each missed/slipped trial.

(3) If the recorded time exceeded two standard deviations above this mean, the elapsed time was considered excessive. If not, then this particular trial was ignored in the miss frequency analysis.

The purpose of this procedure was to ensure that miss responses used in the statistical analysis were truly excessive in terms of elapsed time of response. If only those trials showing elapsed times greater than two standard deviations above the mean were counted as miss responses then 97.7% of other trials (including those where subjects responded slowly due to distraction) would be faster than each miss response. Although this had the effect of eliminating 10% of all missed/slipped trials, it was considered a necessary procedure.

Summary

For the experiment, the following hypotheses about common emergency stop pushbuttons were made:

(1) It was suspected that inclusion of a finger guard around a standard pushbutton could increase both the average human response time for activation and the probability of a miss response.

(2) It was suspected that a large mushroom pushbutton could prove superior to a smaller button in terms of average response time and miss frequency.

(3) It was suspected that further improvements in average human performance could be achieved

by redesigning the standard mushroom push-
button.

The experiment was designed to test the validity
of these arguments.

EXPERIMENTAL RESULTS

The following results for the eight different arrangements of emergency stop devices were obtained:

Mean Response Times ($\bar{X}$) in 1/100 Seconds

Arrangement	$\bar{X}$	s
A - 7/8 Inch Guarded Pushbutton	83.65	10.40
B - 7/8 Inch Unguarded Pushbutton	72.75	12.79
C - 3 Inch Standard Mushroom Pushbutton	67.92	11.57
D - 3 Inch Standard Mushroom Pushbutton (Opposite Hand)	69.13	13.81
E - 3 Inch Standard Mushroom Pushbutton (Greased)	72.30	15.93
F - 3 Inch Experimental Mushroom Pushbutton (Greased)	71.71	11.59
G - 3 Inch Standard Mushroom Pushbutton (Greased + Blindfold)	76.19	16.12
H - 3 Inch Experimental Mushroom Pushbutton (Greased + Blindfold)	74.73	14.32

Table 5-1

Statistical Significance of Observed Differences

Test Pair	Test Parameter	Value 1	Value 2	Difference	Significance Level
A - B	Means	83.65	72.75	10.90	99.9%
B - C	Means	72.75	67.92	4.83	99.5%
C - D	Means	67.92	69.13	-1.21	not significant
E - F	Means	72.30	71.71	0.59	not significant
G - H	Means	76.19	74.73	1.46	not significant
A - B	Misses	20	8	12	96.7%
B - C	Misses	8	9	-1	not significant
C - D	Misses	9	6	-3	not significant
E - F	Misses	21	14	7	not significant
G - H	Misses	38	13	25	99.9%

Note: Not significant means that the statistical significance did not exceed 95%.

Table 5-2

Computed "t" Values of Paired Comparisons

Test Pair	Test Parameter	Computed "t" Value
A - B	Means	9.73
B - C	Means	3.31
C - D	Means	1.19
E - F	Means	0.37
G - H	Means	1.21
A - B	Misses	2.26
B - C	Misses	-0.23
C - D	Misses	0.83
E - F	Misses	1.10
G - H	Misses	3.76

Note: Degrees of freedom (d.f.) = 30.

Table 5-3

Response Frequencies

Arrangement

Response Time (1/100 sec)	A	B	C	D	E	F	G	H
31 - 35	0	0	0	0	0	0	0	1
36 - 40	0	1	1	0	7	1	3	5
41 - 45	0	5	7	8	11	8	9	10
46 - 50	3	22	17	37	20	26	20	23
51 - 55	4	47	77	59	49	29	30	31
56 - 60	15	61	95	80	77	80	62	58
61 - 65	30	95	122	107	99	88	77	79
66 - 70	65	86	114	110	95	113	82	71
71 - 75	86	81	55	68	83	91	73	81
76 - 80	110	74	58	60	50	60	69	77
81 - 85	77	46	21	24	27	37	50	43
86 - 90	63	35	15	20	28	29	45	38
91 - 95	42	22	6	14	20	17	29	35
96 - 100	49	17	7	6	18	10	16	19
101 - 105	30	8	4	6	7	10	9	17
106 - 110	15	6	5	5	5	2	13	6
111 - 115	12	3	2	1	3	3	9	7
116 - 120	3	4	4	4	4	7	3	4
121 - 125	2	0	3	2	4	1	3	4
126 - 130	7	2	0	1	1	2	1	1
131 - 135	0	1	2	3	3	0	2	0
136 - 140	4	2	2	1	1	1	5	3
141 - 145	0	0	1	1	1	2	1	2
146 - 150	0	0	0	0	1	0	1	1
151 - 155	0	1	0	0	0	0	1	1
156 - 160	0	0	0	1	1	0	2	0
161 - up	3	1	2	2	5	3	5	3

Table 5-4

Miss Responses

Arrangement	Frequency	Mean Response Time ($\overline{X}$)	s
A	20	122.5	39.20
B	8	115.0	21.63
C	9	123.3	20.65
D	6	131.7	19.33
E	21	122.2	29.95
F	14	128.5	28.55
G	38	130.4	51.80
H	13	125.4	17.78

Note: Mean response times in 1/100 seconds.

Table 5-5

Frequency Distribution: Arrangement A, 7/8 inch Guarded Pushbutton
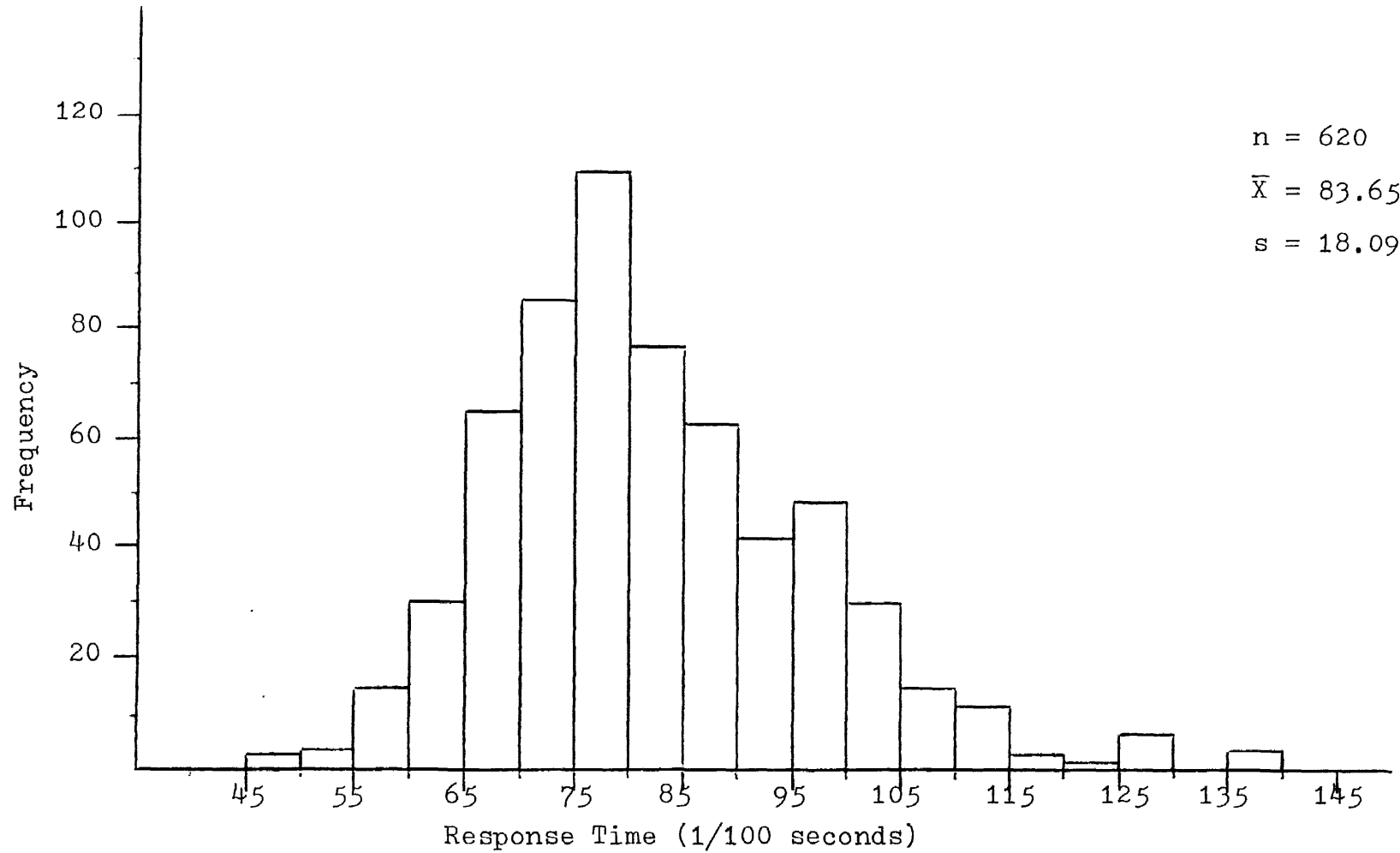
n = 620

$\bar{X}$ = 83.65

s = 18.09

Frequency

Response Time (1/100 seconds)

Figure 5-1

Frequency Distribution: Arrangement B, 7/8 inch Unguarded Pushbutton

n = 620

$\overline{X}$ = 72.25

s = 16.34
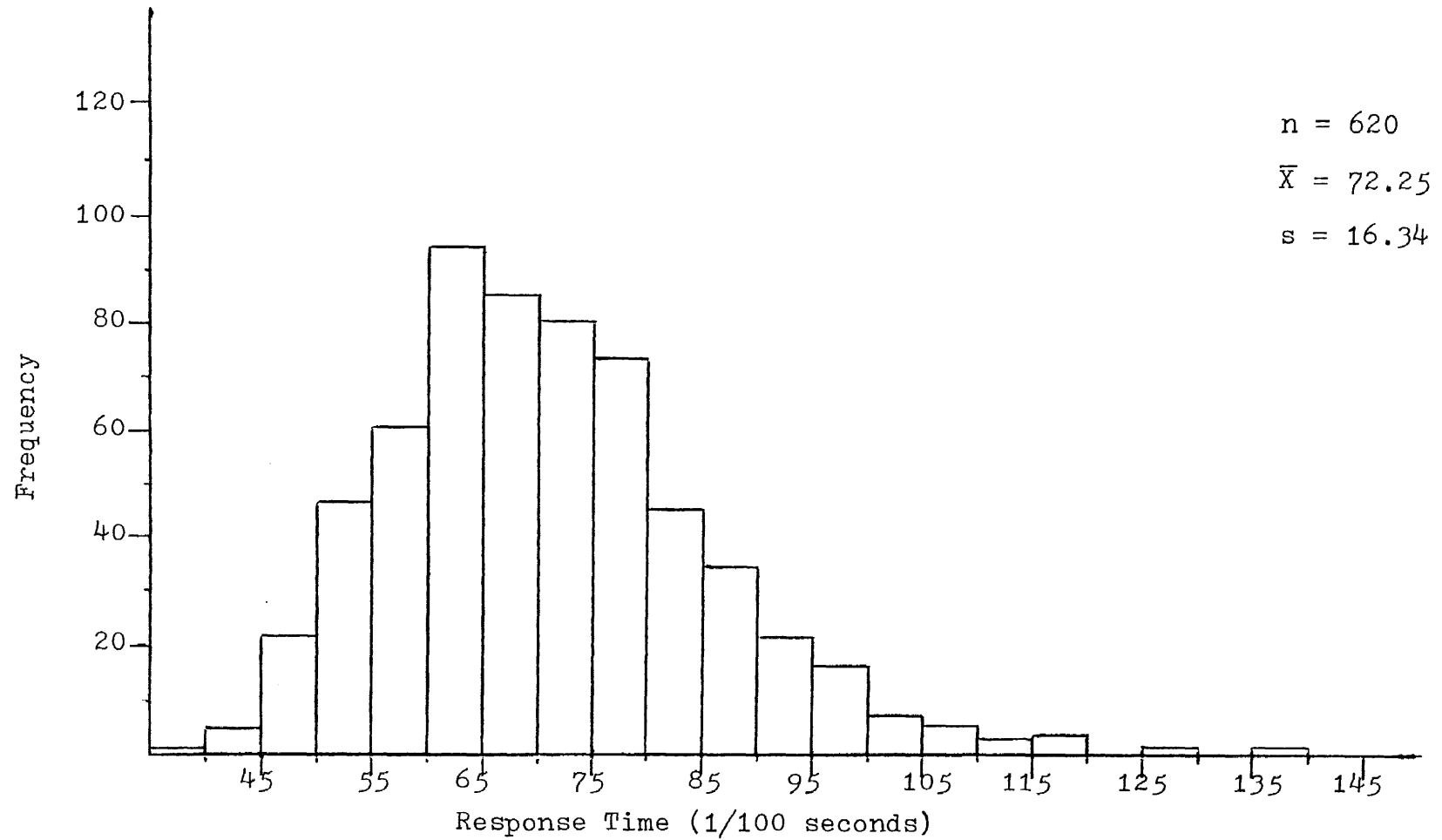
Figure 5-2

Frequency Distribution: Arrangement C, 3 inch Standard Mushroom Pushbutton

n = 620

$\overline{X}$ = 67.92

s = 15.47

Response Time (1/100 seconds)

Figure 5-3

n = 620

$\overline{X}$ = 69.13

s = 17.64

Response Time (1/100 seconds)

Figure 5-4

Frequency Distribution: Arrangement E, 3 inch Standard Mushroom Pushbutton (Greased)

n = 620

$\overline{X}$ = 72.30

s = 26.01

Frequency

Response Time (1/100 seconds)
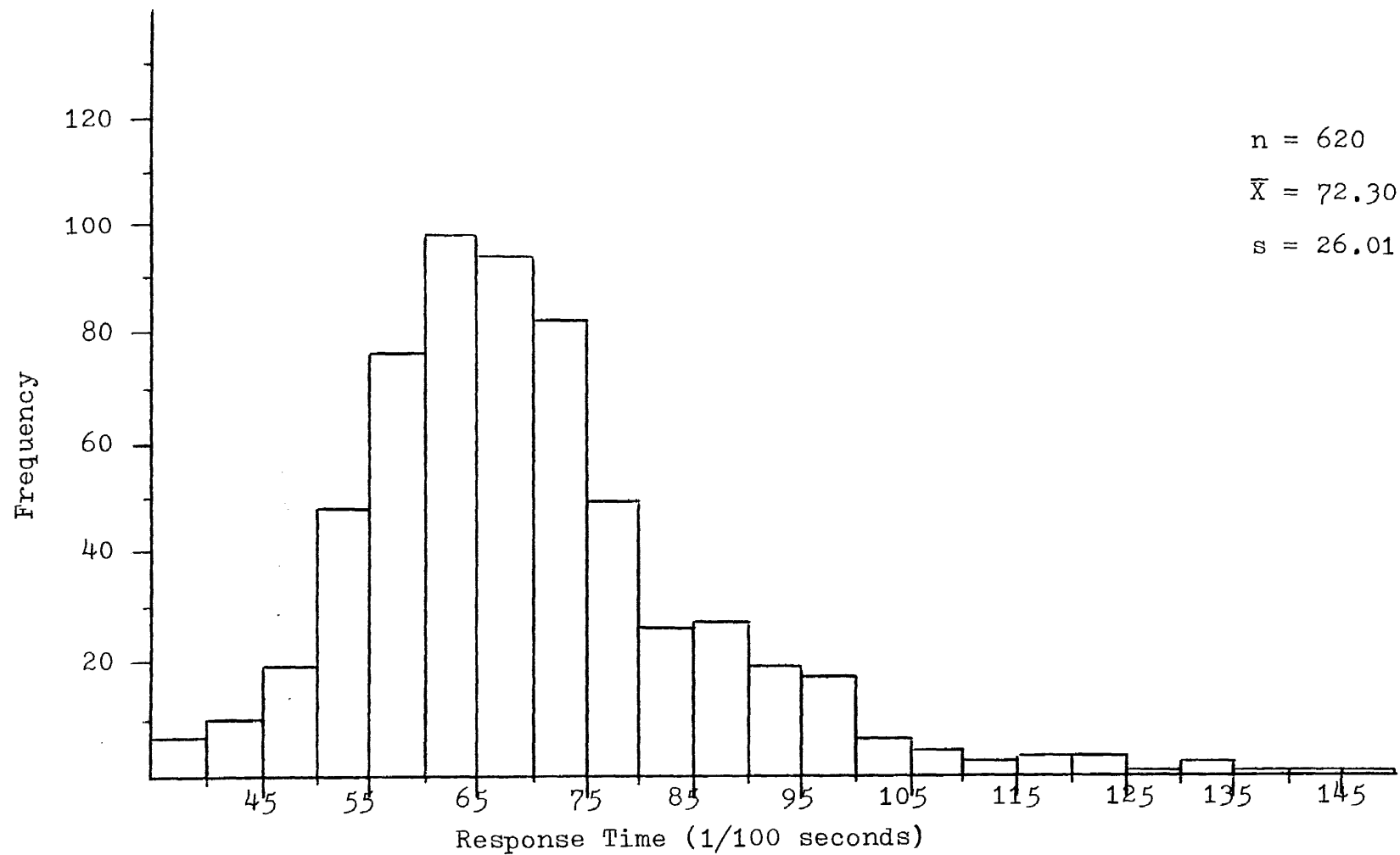
Figure 5-5

Frequency Distribution: Arrangement F, 3 inch Experimental Mushroom Pushbutton (Greased)

n = 620

$\bar{X}$ = 71.71

s = 19.05

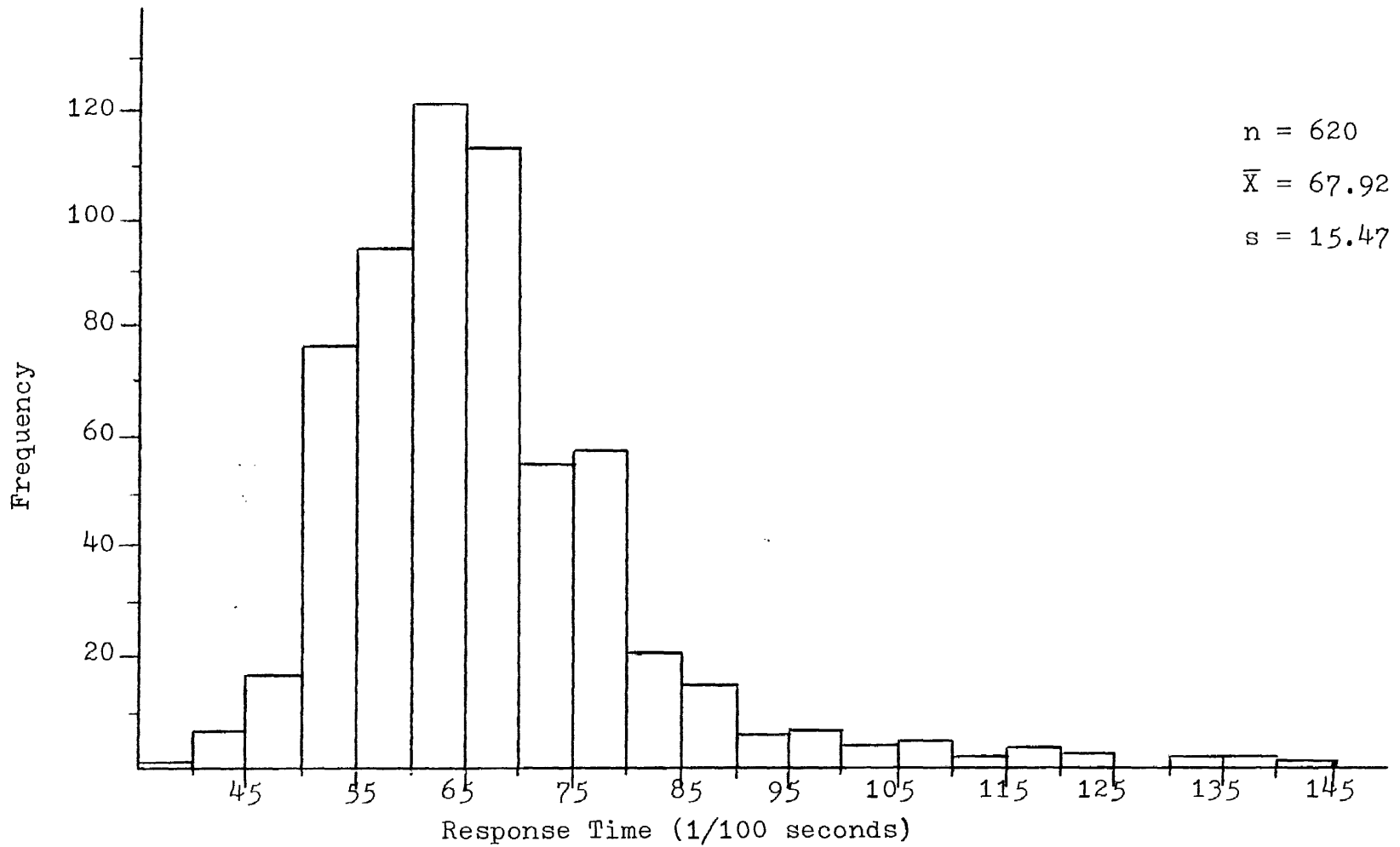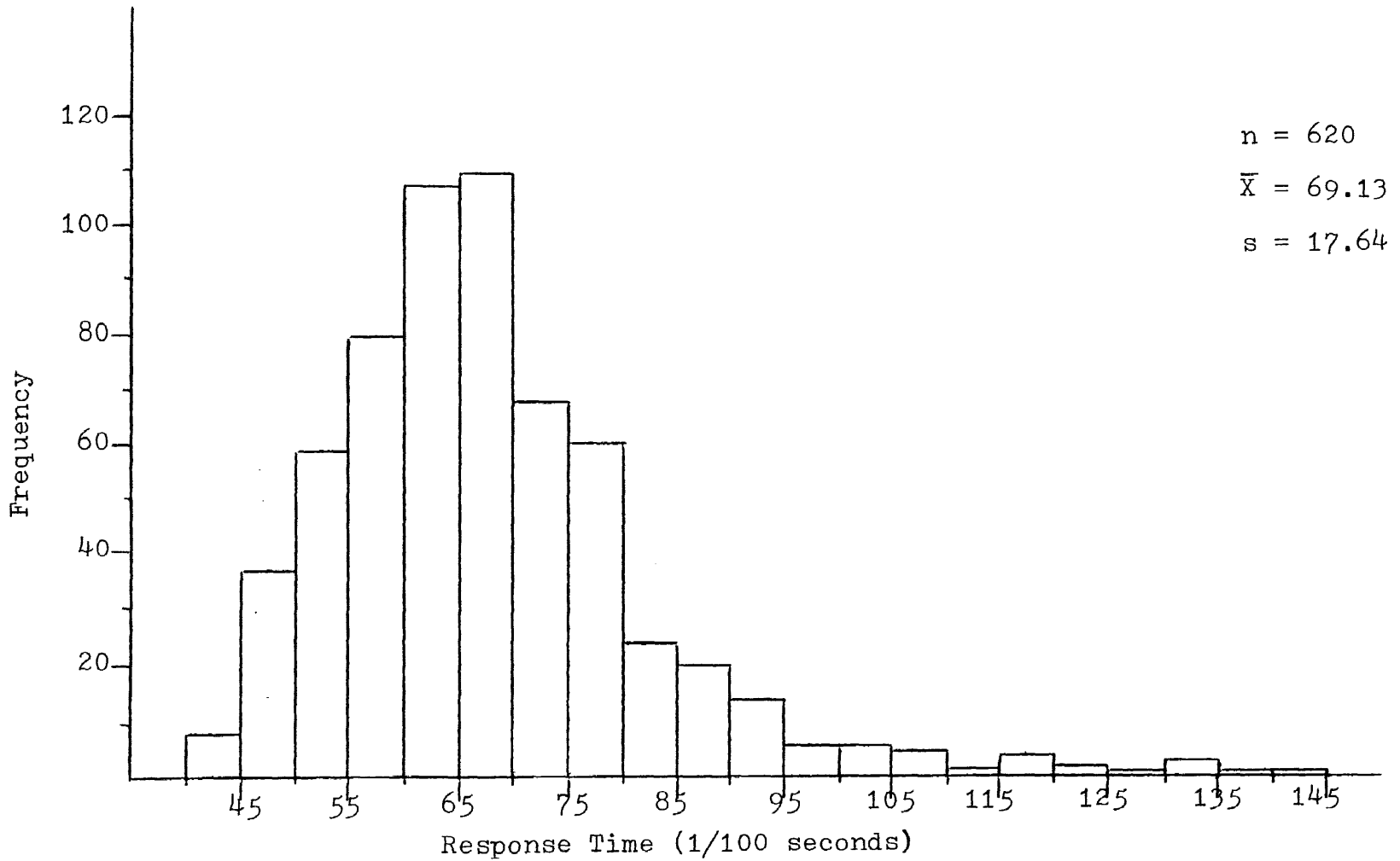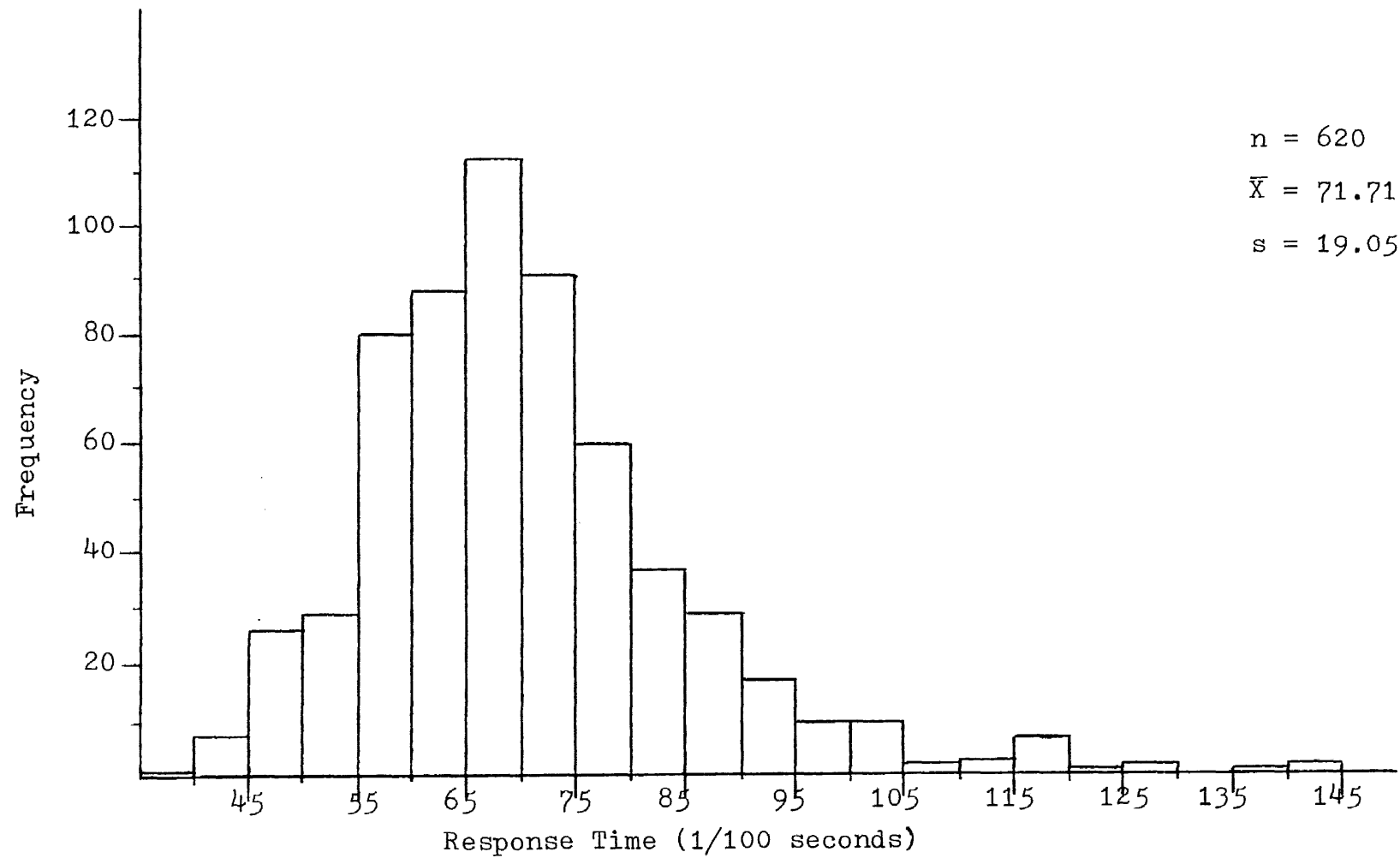Response Time (1/100 seconds)

Figure 5-6

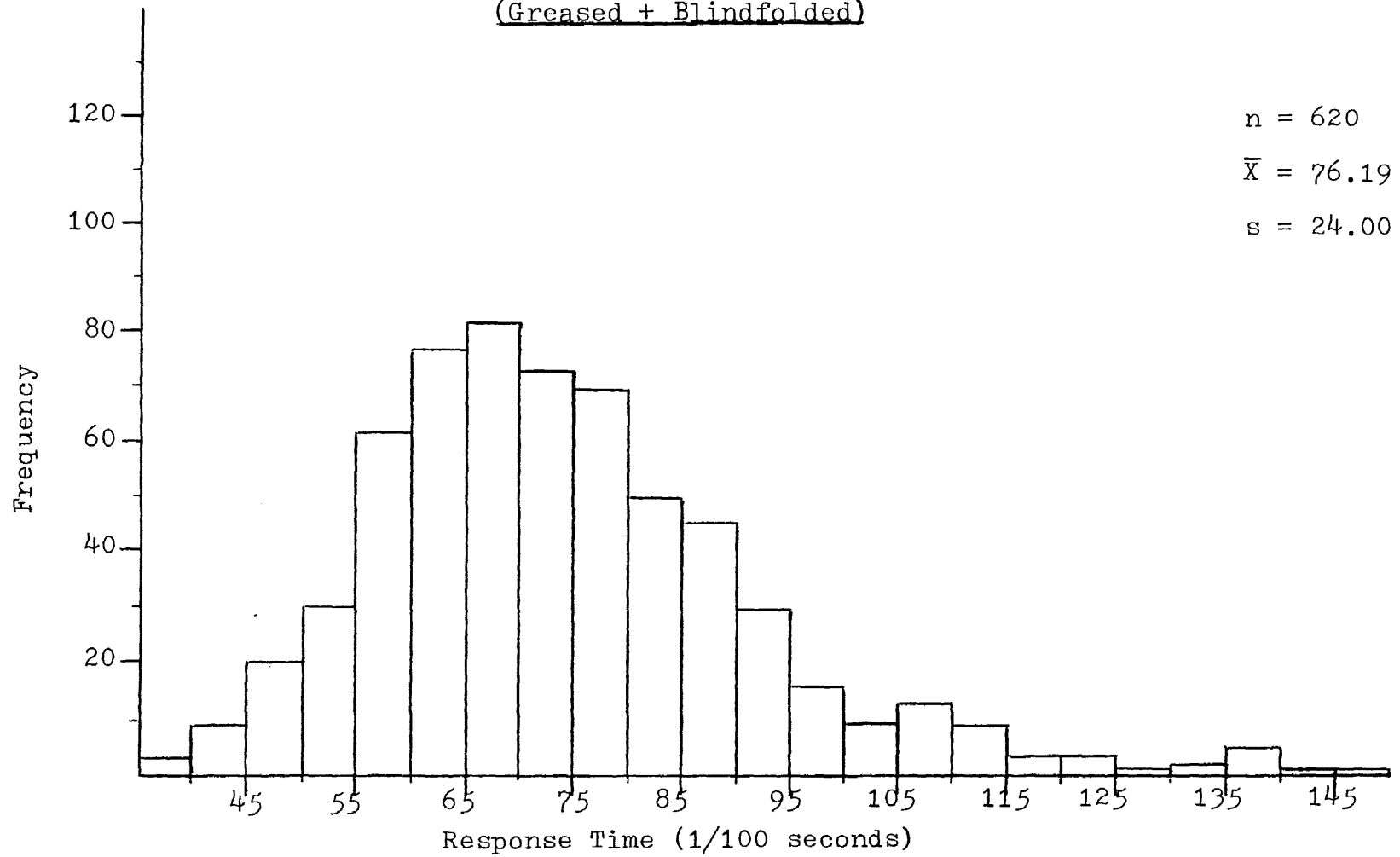Frequency Distribution: Arrangement G, 3 inch Standard Mushroom Pushbutton
(Greased + Blindfolded)

Figure 5-7

Frequency Distribution: Arrangement H, 3 inch Experimental Mushroom Pushbutton
(Greased + Blindfolded)

n = 620

$\bar{X}$ = 74.73

s = 18.95

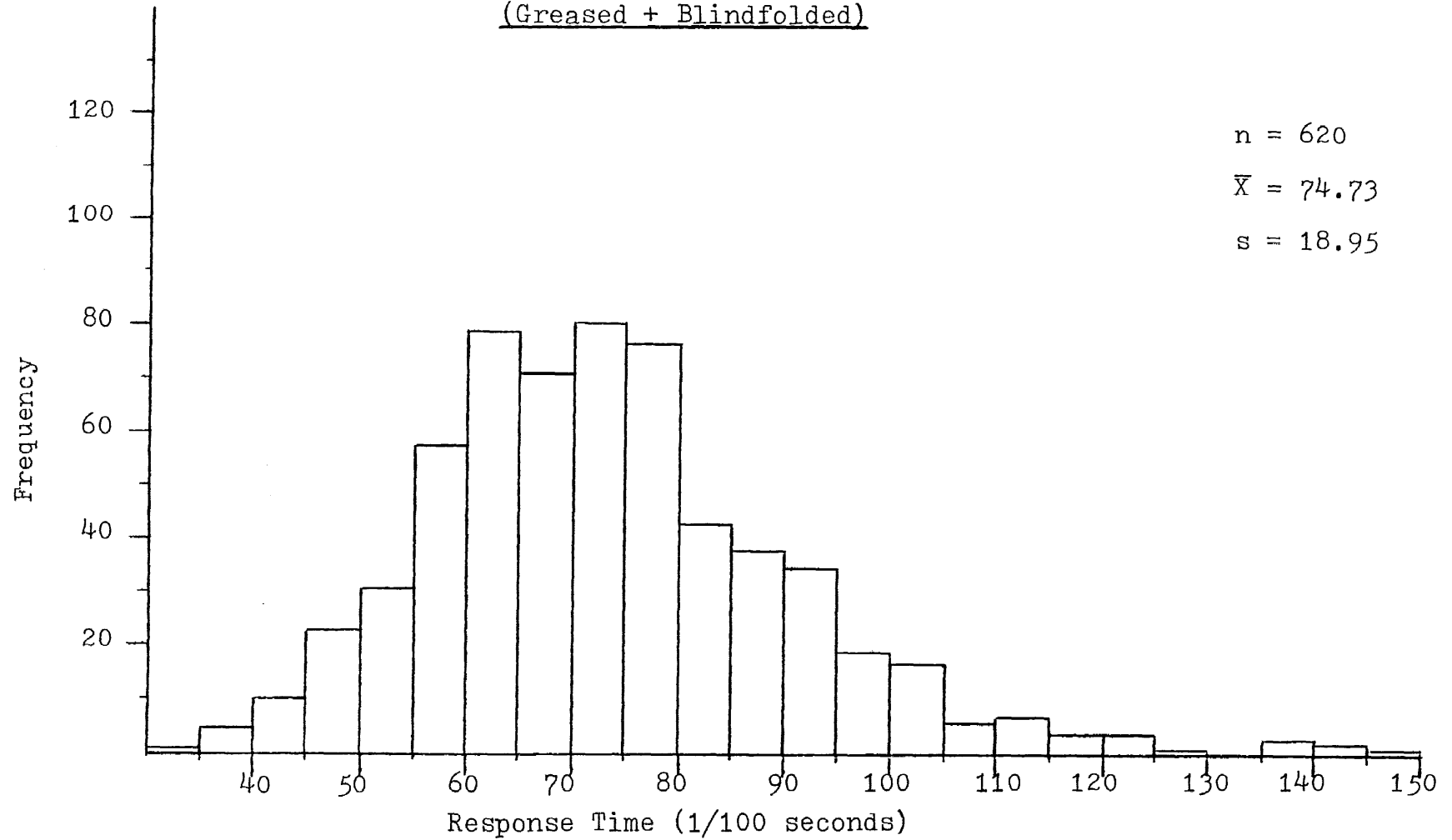Response Time (1/100 seconds)

Figure 5-8

CHAPTER VI

DISCUSSION AND CONCLUSIONS

Experiment Phase I

For the four different arrangements of emergency
stopping devices tested in phase I of the experiment,
the following major conclusions were reached:

(1) The inclusion of a protective collar guard around
a standard 7/8 inch pushbutton seriously detracts
from a human being's ability to quickly and con-
sistently activate the device. This was shown
by a 15% increase in average system response
time with a statistical significance well in ex-
cess of the 99.9% level. Furthermore, inclusion
of the guard was shown to increase the frequency
of miss response by a factor of 2.5 to 1, this
being in excess of the 95% level of statistical
significance. The effect of a miss was observed
to be an increase in total system response time
from an average of 0.84 second to an average of
1.23 seconds or an increase of about 46% for the
guarded pushbutton. Probability of a miss re-
sponse was 0.032 for the guarded pushbutton and
0.013 for the identical button with the guard

removed. Lastly, one subject was observed to miss the guarded pushbutton twice in succession during a single trial. Total response time for this trial was 2.45 seconds. A double miss was not observed at any other time during the 4,960 trials of this experiment.

(2) The 3 inch standard mushroom style pushbutton was observed to have a shorter mean response time than the unguarded 7/8 inch button by about 6.6%; the null hypothesis that the means were the same was rejected at greater than 99.5% level of statistical significance. The null hypothesis that frequencies of miss response were the same for these two devices could not be rejected and, in fact, they were observed to be about equal. Probability of a miss response for the 3 inch standard mushroom pushbutton was 0.015 compared with 0.013 for the 7/8 inch unguarded button.

(3) The null hypothesis that mean response times were the same when using favored versus non-favored hands to activate a 3 inch standard mushroom style pushbutton could not be rejected at greater than 95% level of significance. This occurred in spite of a small observed increase in mean response time (1.8%) when shifting to the non-favored hand. Many more trials would be needed to show a significant difference, indeed

if any difference actually exists. Miss probability was 0.010 for the non-favored hand and it was concluded that mean system response time and miss frequency for this device are not dependent on the hand used for activation.

For phase I of the experiment one obvious conclusion is: a 7/8 inch unguarded pushbutton is superior to a guarded button in terms of the average human-machine system response time for activation. Secondly, the larger mushroom style pushbutton is superior to the smaller button. It is assumed that the larger surface area encourages use of a somewhat faster (although less precise) palm strike and off-center hits are effective in activating this device because of rocking motion. Time consuming secondary movements are thereby minimized. Palm strikes can also be used on the unguarded smaller button but this may not be as obvious. Many subjects were observed using fingertips on this device while very few, if any, used anything but palm strikes on the large mushroom pushbuttons. Finally, a near threefold reduction in miss frequency can be obtained by using an unguarded device. This could become a critical factor during a true emergency response.

Experiment Phase II

During testing for this experiment it was expected that the 3 inch standard mushroom style pushbutton would give superior results in terms of average response time. Indeed, during analysis of phase I data this hypothesis was shown to be statistically significant and did not come as a surprise; but miss frequency did not prove superior with this device. From personal experience and research by the experimenter it was suspected that, whatever type of device is used, under emergency conditions, manual stopping of equipment will always be associated with some probability (no matter how small) that the human being responding will not complete the response. In other words, the person might fail to stop the machine on the first try (miss) under some combination of physical and emotional stress. Furthermore, the developing situation might not allow time for this person to try again. This situation was deemed the most serious, therefore, an effort was made to improve the standard mushroom button design in order to reduce miss frequency.

It has already been concluded that the standard mushroom button allows more rapid activation because of its sensitivity to off-center hits. Also, as shown in the experiment by Brown and Slater-Hammel, secondary movements, similar to those needed to position fingertips in space for the 7/8 inch pushbutton, can often add significantly

to system response time. These movements do not seem to be associated with the palm strikes commonly used on large mushroom pushbuttons; however, occasionally a hit will be sufficiently off-center that a hand will slip off the rounded edge of the button before electrical switch contact is made. The result is a miss.

It was suspected that the surface of curvature should not be consistent along the entire cross section of the device. In other words, if the standard mushroom button were cut vertically through the center and a side view drawn, the surface of the button would form an arc of a perfect circle. It was decided to modify this arc by including a horizontal edge; a button of this shape was manufactured and the resultant forces during off-center hits for the two devices are shown in figure 6-1.

In order to test the hypothesis that the surface of the experimental mushroom head was superior to the standard head, some method of increasing frequency of miss for both devices was needed. It was decided to adjust the system variables as follows:

(1) Spring pressure to activate the device was
increased; this had the effect of requiring
harder strikes to make electrical switch con-
tact. This condition was not considered un-
reasonable because, with age, accumulation of
dirt, and degradation of sliding surfaces,

Forces on Pushbutton Surfaces

Standard Mushroom

F = Force applied from off-center hit

F_r = Radial Component
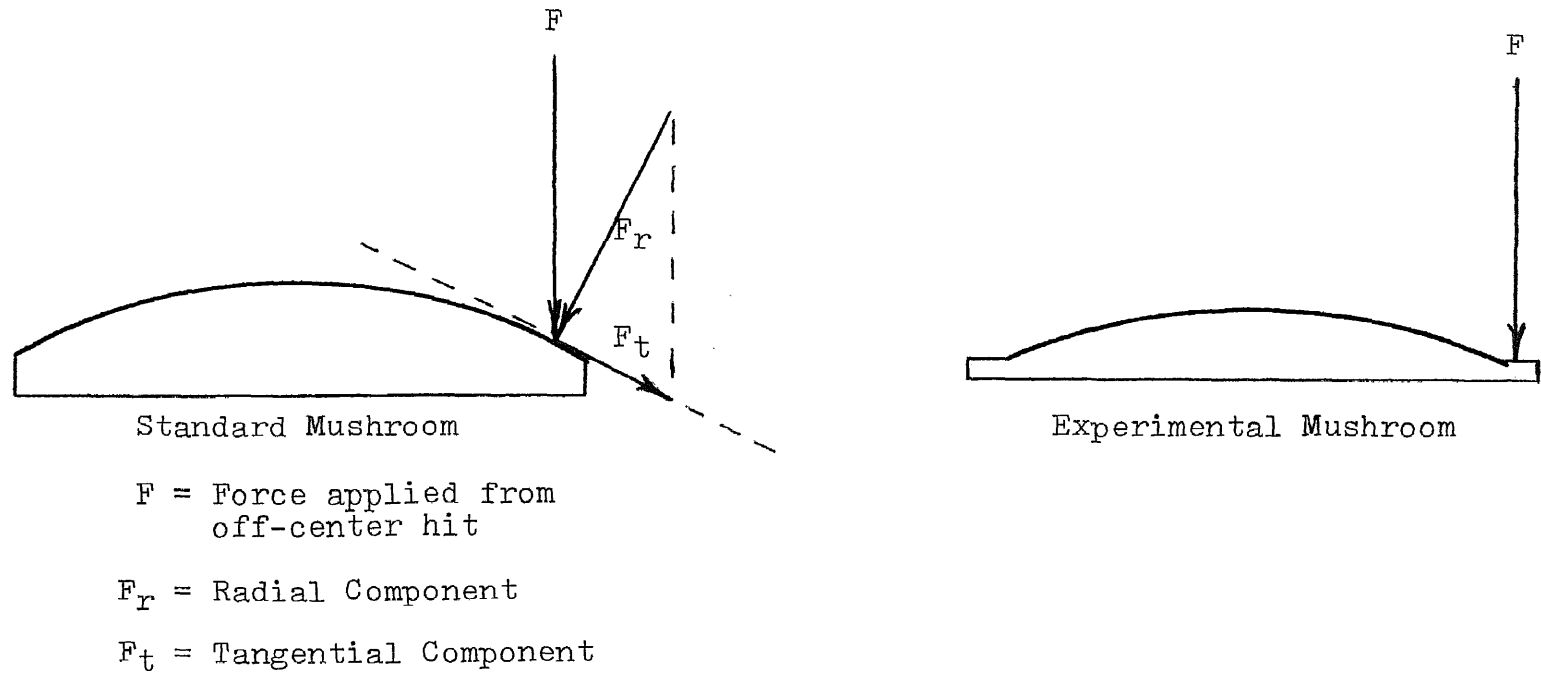
F_t = Tangential Component

Experimental Mushroom

Figure 6-1

pressure required for activation of industrial pushbuttons could easily increase.

(2) Surfaces were made extremely slippery by thoroughly coating with silicone spray lubricant. This condition did not seem unreasonable because many manufacturing environments use spray silicone or other lubricants on work parts and machines. Excess lubricant could easily coat the emergency stop button and/or the operator's hands without notice.

(3) Subjects were blindfolded for parts of the experiment. It was thought that this condition would increase the probability that palm strikes would be sufficiently off-center to produce miss responses. This was considered a reasonable simulation of an emergency situation (such as a human entanglement) where the person involved must reach instinctively for the emergency stop device without being able to see it.

The major conclusion from phase II of the experiment was that miss frequencies were higher for the standard mushroom pushbutton design. The null hypothesis that miss frequencies were the same for the standard and experimental designs during blindfolded response was rejected at greater than 99.9% level of statistical significance. It was concluded that the experimental head was superior in prevent-

ing misses during the extreme conditions of this part of the experiment; namely, the high activation force required, slippery surfaces, and lack of visual contact. Miss probabilities were 0.061 and 0.021 for the standard and experimental heads respectively.

Although, in the non-blindfolded condition, miss probabilities were observed to be 0.034 and 0.023 for the standard and experimental heads respectively, the observed difference was not sufficient to reject the null hypothesis at greater than 95% level of significance. It was concluded that many more trials would be needed to show a significant difference in this case.

As expected, average response times for the standard and experimental heads did not differ sufficiently for rejection of the null hypothesis. It was concluded that, since both mushroom heads were 3 inches in diameter, there would be no reason to expect any differences in average response times; therefore, it was concluded that they were equal.

Frequency Distributions

Frequency distributions for each of the eight experimental arrangements are included in chapter V. Analysis of these distributions indicates that there is likely some minimum value of response time before which no human emergency response could ever be expected. Clearly, faster

responses than this minimum, which appears to be about 0.3 second for this experiment, could indicate some anticipatory condition to stimulate response before the alarm. Non-stimulated responses of this type were noted several times during the experiment when subjects pressed the button without any signal being given. However, it is believed that good performance by the experimental assistant at keeping subjects occupied with the auxiliary task prevented anticipation from affecting the results.

These distributions also indicate that there is likely no corresponding maximum value of response time after which no human emergency response could ever be expected. The longest response time observed for this experiment was 4.40 seconds. This occurred during a trial when the subject was deeply engrossed in some particular train of thought. This distracted condition combined with miss responses and periods of indecisiveness could conceivably skew frequency distributions even more seriously under true emergency response situations. No attempt was made to analyze these positively skewed distributions any further than the above speculations.

Conclusion

For this study, many major conclusions were reached regarding emergency stop pushbuttons commonly used on industrial machines. These will not be repeated here; the

reader is referred to the summaries in chapters II and III and the previous discussion. However, the clear superiority of an unguarded pushbutton and especially the large mushroom style button in both average system response time and miss frequency provides the focus for a concluding argument.

Guarded pushbuttons should not be used as emergency stopping devices on machines. If prevention of accidental stopping of machines (bumping) is a machine design criterion, then emergency stop pushbuttons should be guarded by location. Furthermore, the location should be easily accessible and within reach of an operator in the normal operating position. If this is incompatible with the need to prevent bumping of emergency stop buttons, then bumping as a criterion should be sacrificed in favor of operating convenience.

Also, the author has seen many cases where dangerous machinery is stopped and started by two adjacent guarded pushbuttons on one panel; frequently the dual pushbutton station shown in chapter I is used. These should be replaced. The increase in system response time and miss frequency for guarded pushbuttons plus the possibility that a frightened operator could push the wrong button, justify rejection of this popular arrangement as a control panel.

Since the experiment in this study utilized emergency stop pushbuttons mounted on an angled control pan-

el which could be considered an optimum location for activation, no attempt was made to apply the results to buttons mounted in non-optimum locations. This is left for further investigation. However, it could be surmised that the experimental head used in phase II of this experiment might show an even greater improvement in miss frequency when mounted in a less optimum location such as on a vertical panel. On this type of panel the anatomical posture of the wrist might be incompatible with palm strikes; therefore, on vertical panels, operators might be encouraged to use fingertips to activate mushroom pushbuttons. Fingertip strikes would likely require more secondary movement than palm strikes and this could affect miss frequency. Therefore, the hypothesis that the experimental head mounted on a vertical panel could reduce miss frequency remains to be tested.

The focus of this study has been on ergonomic principles and their proper application to design and placement of emergency stopping devices. One might wonder how so much emphasis can be placed on such simple devices; for clearly, there is not much that can be done to improve what is already in use. However, the fallacy of this notion becomes apparent when the results of this experiment are considered. How many machines today still use the standard 7/8 inch guarded pushbutton as an emergency stopping device? Even for such a simple device, improvements can be made when ergonomic principles are ap-

plied and concern for the human operator is given during design of machines.

CHAPTER VII

CRITICAL ANALYSIS: READERS' COMMENTS

An important aspect of technical report writing is
the solicitation of constructive criticism regarding the
research. These comments, when given by persons knowl-
edgeable in the field, can be used not only to evaluate
the work but also to generate further interest. Histor-
ically it has been shown that questions have often arisen
during the course of technical research which could not
have been answered without further study. Later experi-
menters often explored these themes. Therefore, readers'
comments are important for evaluation and to promote con-
tinued interest in the field.

The following readers have provided comments and
their critiques are included for reference:

Professor James L. Smith, Ph.D., P.E.
Industrial Engineering Department
Texas Tech University

Mr. Frank Bastion, CIH
Certified Industrial Hygienist
Clayton Environmental Consultants, Inc.

Mr. Nabil J. Bejjani, MS
Civil Engineer
Louis Berger & Associates

Texas Tech University

Department of Industrial Engineering
Lubbock, Texas 79409-4130/(806) 742-3543

April 5, 1986

Mr. Robert P. Guinter

Dear Mr. Guinter,

I have read your thesis and found it to be well written and an appropriate research effort for a Master's degree with an ergonomics specialty. The literature review was extensive and provided the appropriate background for the thesis.

The experimental method was adequate, although it did produce a few questions that I feel should be resolved. At one point you stated that, "the experimenter recorded a deviation only when absolutely certain that one had occurred" (p. 20 of CH 4), yet 5 pages later you describe a procedure to test the "legitimacy of any suspected deviation". These statements appear to be in conflict and I would suggest a brief rationale of why the legitimacy test was felt necessary, and the effect of the procedure on the data. ie., how many "MISSES" were eliminated using this procedure? Another point that I feel needs to be addressed is the manner in which a "normal diversity of industrial activity was simulated". You hypothesize that "no mental concentration on response time could be maintained", although later on the same page (p. 10, CH 4) you state that, "no trials were observed to take longer than three minutes to complete". Is the three minute maximum trial time long enough to remove all anticipation by the subject and to indeed simulate the "normal diversity of industrial activity"?

The statistical analysis seemed appropriate for the experiment. I would like to see explanations for a couple of items in your results section. First, in Tables 5-2 and 5-3, why weren't the MISSES for the C-D response comparison included? You appear to discuss the C-D comparison in your Discussion of Results section. Secondly, how can the B-C MISSES in Table 5-2 be "not significant" if in Table 5-3 the "t" value for B-C MISSES was "not computed"? If it was, in fact, not computed, why not offer a brief explanation for its exclusion?

The conclusions seem to logically follow from the results of the experiment. I think that CHAPTER 5, Discussion of Results, is in reality a part of the conclusions. I would suggest that the Discussion of Results section address issues such as what data were included and excluded from analysis and why, and the rationale for the manner in which the data are represented, ie., tables, response frequencies, and frequency distributions. Finally, a suggestion: Here at Texas Tech we have started to require that students include their raw data in an appendix so that future researchers can use the data if they desire.

Overall, I feel that the thesis was well done and hope that you find my comments helpful. I have enclosed a brief description of our ergonomics program here at Texas Tech to provide you with a little background on the kinds of ergonomics efforts in which I am involved. I would like to receive a final copy of your thesis when it becomes available. If I can be of further assistance, please let me know. Good luck on your defense and with your future endeavors in the ergonomics area.

Sincerely,

James L. Smith, Ph.D., P.E.,
Associate Professor

Professor James L. Smith, Ph.D., P.E.
Department of Industrial Engineering
Texas Tech University

Dear Professor Smith:

After speaking with my thesis advisor concerning your
many valuable comments and suggestions, it was decided
that I should write you a formal letter addressing these
issues and include a copy with your critique in the final
report. Therefore, this letter is in addition to the
thank-you letter I already sent and may contain some of
the same information.

Concerning the question of raw data being included with
the report, it was decided that the quantity of pages
would seriously increase the size of an already lengthy
report. Therefore, raw data will not be included. How-
ever, my advisor requested that the raw data be included
with your copy of the final draft and the original data
sheets will be kept on file in the Industrial Engineering
department here at NJIT. If anyone should need these data
for further research the department will make them avail-
able on request.

As to the conflicting statements in chapter IV you are
absolutely correct. After considering this point I real-
ized that my wording did not accurately convey the idea
I was trying to communicate. How could an experimenter
sitting behind the subject be "absolutely certain" that
a miss/slip had occurred? In reality, there is no way to
be absolutely certain unless each response was videotaped
and later scrutinized in detail. Since this was not done,
the experimenter could only become mentally convinced that
a deviation had occurred after considering the visual and
audible effects of each response and the recorded elapsed
time of each trial. Therefore, each suspected deviation
required a mental decision on the part of the experimenter
which did allow some small probability of error. I believe
this idea is more clearly established in the revised word-
ings. Also, it was concluded that, even if a subject
missed or slipped during a response this event only became
important if it seriously increased the total elapsed time

Professor James L. Smith, Ph.D., P.E.
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April 17, 1986

of response. If a miss occurred but then the subject
recovered within a sufficiently short time period to
stop the clock quickly, then the trial should not be
included with the miss frequency analysis because, clear-
ly, it would not have seriously degraded a true emergency
response. Only those misses/slips that seriously in-
creased the elapsed time of response were wanted. This
was the reason a procedure for eliminating non-excessive
deviations was devised. Hopefully, this idea is now more
clearly conveyed after rewording.

Tables 5-2 and 5-3 have been expanded to include the data
for B-C and C-D misses that were not included in your copy
of the draft. After reading your comments, I decided that
a "t" test of this information was indeed required if the
result was later to be reported as "not significant." It
was not a good scientific method to assume a statistical
result no matter how trivial the computation or obvious
the result might appear. Also, the typographical error
in table 5-3 was corrected; it was B-C misses that should
have been labeled "not computed," not A-B misses. Now all
"t" values have been computed and reported in the table.

Your comments about the discussion and conclusions have
resulted in these two chapters being combined. Also, ex-
cept for the procedure to eliminate non-excessive missed/
slipped trials from the miss frequency analysis, there was
no attempt made at any time to eliminate any subjects'
individual or averaged response times. The comments on
pages 80 and 108 reflect my opinions on this matter.

Finally, for the rationale of data representation in chap-
ter V, these tables and figures were included to represent
the data in every way that seemed logical and informative.
During my literature search I found that many experiment-
ers failed to include significant information about their
data. Perhaps this reflects a need for fewer pages and
concise data representation for journal publication. In
writing a thesis, I am not restricted in this manner and
my tables and figures were included so that future exper-
imenters will not be hampered when reviewing my research
(as I was when reviewing others').

Professor James L. Smith, Ph.D., P.E.
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Again, I would like to express my gratitude for your
timely and extensive comments concerning my research
effort. I have had ample time to address each issue
you raised and many pertinent changes to the final
draft have been made. I expect to have copies of the
final draft made within the next two weeks and I will
send you one shortly thereafter. Thanks again and I
extend my very best regards.

               Very truly yours,

               Robert P. Guinter

Robert P. Guinter   May 5, 1986

Dear Bob:

I read your thesis 'Emergency Stop Devices For Industrial
Machines And The Human Factors Of Emergency Response' and
found it an interesting and informative study of an important
safety issue.

Clearly, there is more that can be done to minimize
the incidence and severity of industrial machine accidents.
The lack of uniformity in emergency stop devices points up
the need for safety and design professionals to cooperate in
incorporating ergonomic principles in the design and retrofit
of industrial machines.

The experiments described affirmed the dogmatic belief
that small, guarded stop buttons are more difficult to success-
fully activate than large, unguarded buttons. Beyond this, how-
ever, the study defines and quantifies different human response
factors involved. For example, the total human response time
includes contributions due to recognition of the emergency,
the motion to activate the stop device, the possibility of
missing or slipping-off the stop button, the possibility of
identifying the wrong button, and the physical action required
such as single digit versus palm activated buttons. This detailed
treatment brings to light new ideas such as the proposed revised
mushroom button design which can decrease the response time.

I have a suggestion regarding the motivation of experi-
ment subjects. Ideally, subjects will respond in the experi-
ment the same as they would in an emergency situation. The
question is how to elicit crisis motivation without endanger-
ment. A possible solution would be to chose the subject popula-
tion from a group that is motivated by monetary gain (eg. college
students). The subject would compete for a reward of some sort.
I'm not certain just how this would be implemented, but I
think the idea of trying to simulate some of the emotions
which motivate a real-life operator in a crisis situation
could benefit future experiments.

page two

     I believe this thesis is a worthy addition to the body of
information concerning industrial safety. My best wishes for
your continued success.

Sincerely,

B.F. Bastian, CIH
Clayton Environmental Consultants, Inc.

Nabil J. Bejjani, M.S.C.E.

May 5, 1986

Mr Robert Paul Guinter

Dear Mr Guinter:

I had the pleasure to read your Master Thesis on "Emergency Stop Devices
and Human Response".

The work was done with professionalism reflecting a well structured
handling and discussion of a very relevant and up-to-date topic in Ergonomics.
Moreover, the good syntax helped the refined English writing style in
presenting the subject matter as a clear and easy to understand one, although
some ideas were stated in an ambiguous way. The formatting and presentation
are inviting and clean, except for some drawings (figures) which lack
explanation and mainly captions.

Although not displayed in a standard form, the scientific aspect of the
experiments and their results are accurate and sufficiently elaborate for the
purpose of the study. The statistics   part could include a tabulation of
Means, Standard Deviations and Ranges (i.e. minima and maxima) of the
corresponding results and observed data, in order to be more technical.

But most of all, as the intent of this thesis is to serve as a reference
material to the industry, an economical additive, coupled with a sharp safety
measure advice against vandalism will make your findings even more attractive
to Management in the industrial world.

All the aforementioned remarks do not interfere with the intrinsic value
of the research work, which is very infomative about the subject treated. It
is thoroughly backed by relevant references and exhaustively encompasses all
the sides of the "Emergency Stop Devices and Human Response" issue.

I wish you good luck, with confidence,

yours truly,

Nabil J. Bejjani

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