Bellamy

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NOT WAVING BUT DROWNING: PROBLEMS OF HUMAN COMMUNICATION IN THE DESIGN OF SAFE SYSTEMS

Linda J. Bellamy*

This paper emphasises the importance of taking task related interpersonal communication into account when designing safe systems. Potential weaknesses in such communications are illustrated using an information processing model. Specific problems are highlighted by giving examples of errors that have preceded major accidents. The implication is that use of a natural language is a highly imperfect means of accurately communicating task related information, particularly in complex communication structures. Such imperfections need to be recognised and eliminated and the communication process sufficiently formalised to minimise error.

INTRODUCTION

Ergonomics has not progressed very far in extending the concept of communication beyond that of the interaction between man and machine. There is not an area of ergonomic study that can be readily distinguished as principally concerned with task-related communication between people. The design of procedures, for example, has received little attention in this respect. Although general principles can be applied, such as those derived from studies concerned with the presentation of written information (e.g. Wright and Barnard, (1)) procedures must often be modified according to their shortcomings as discovered when they are actually in use, for example maintenance procedures (Losee et al (2)) and emergency procedures in nuclear power plants (Brune and Weinstein,(3)). It is frequently not only the basic design principles of the procedures that are at fault, such as failing to use short simple sentences or having a "check-off" facility, but rather a failure in accuracy, completeness or organisation of content, or even a failure to have or to use a formal procedure at all. Taking a recent example, the Radiochemical Inspectorate (Great Britain: Department of the Environment, (4)) concluded with regard to the leak of radioactive waste from Sellafield that:

> "The procedure for communicating information between managers by way of manuscript entries in log books appears to us inadequate, prone to error and not sufficiently formalised."(p.13)

Similarly, the Health and Safety Executive Report (Great Britain: Health and Safety Executive (5)) suggested it was:

> "because of what appeared to be a failure of communication between shifts."

Failure of interpersonal communication has frequently been a common contributory cause of major accidents. This author has previously highlighted this fact (Bellamy, (6)). When communication errors occur a "mismatch"

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situation can develop between the actual state of a system and the perceived state of the system, leading to a failure on the part of an operator to act within the limits set for normal operation of that system. Some examples of the communication errors found were: beliefs that communication was not necessary, use of an informal communication system, a formal communication system being allowed to lapse, blocked communication channels, noisy communication systems being used and incomplete or inaccurate encoding of information. However, it is not the purpose here to discuss accidents in detail although specific examples of communication error will be given. Rather, the intention is to elucidate how interpersonal communication systems operate and to discuss some of the factors which affect communication reliability. The overall aim is to highlight the need for improved systems of task related information transmission and exchange between people.

INTERPERSONAL COMMUNICATION AND THE INFORMATION PROCESSING MODEL

Shannon's problem, finding solution in the mathematical development of information (or communication) theory (Shannon & Weaver, (7)), was how to determine what sort of signal to send so as best to convey messages of a given type. How could such messages be coded to secure the fastest error free transmission over a given circuit? The same problem exists in considering interpersonal communication; how can the difference between an intended and an interpreted message be minimised in conveying that message over the shortest possible time? In order to answer this question a number of factors have to be considered which can be elucidated in the information processing model (see Figure 1).

The intended message must first be encoded and physically transmitted in the form of a signal. In interpersonal communication this encoding and transmission is achieved by selective use of signs whether written, spoken or gestured. For example, the gestures of a policeman controlling traffic, the sentences, tables and diagrams used in written procedures, or a verbal instruction from a supervisor, all involve the use of signs which are transmitted in different forms. In effective communication the signal acts upon the receiver in such a way as to cause him to select the appropriate behaviour from a set of alternatives in the shortest possible time. There would be an accurate decoding of the signal if for example, the driver turns right in response to the policeman's right turn gesture; in other words, the policeman's selection of sign and the driver's selection of response match.

This encoding-decoding process involves some interesting problems. Natural languages such as English abound with ambiguity. While this allows for subtlety of expression, accurate communication requires a clearly defined context such that the encoded selection of signs by the sender unambiguously indicates the same selection by the receiver. The sender may transmit the message "Ring Janet", but the receiver may know a variety of Janets. The set of possibilities from which the sender selects "Janet" is therefore different to the set from which the receiver makes the selection, and because of this the latter is likely to select the wrong Janet. To reduce error, therefore, it is necessary to specify context or set by saying for example, "Ring Janet in the Ergonomics Unit" or by signing the message, or by any means which specifies the set to which Janet belongs. Although this may seem a rather trivial example it does illustrate the need to formalise communication procedures, where coding and decoding errors can be reduced if the process works within a well defined set of rules of selection resulting in an inflexible closed system (although rules may still be broken, of course). All organisations have rules but these rarely apply to communication systems. When communication systems are open and therefore flexible (unlike the closed traffic directing system used by policemen) they are more prone to error because the set of signs upon which they are based is not effectively finite; neither are the signs free from unwanted or changing associations. Take this example from Barrett (8) querying nuclear power plant communication procedures:

> "[The instructor] replied that there were no directions about communicating between operators - operators must develop their own communications system.... I heard one instructor ask another ... what the temperature was. "It is normal", came the reply. "Don't tell me whether it is normal," said the instructor ...,"tell me what it is."" (p.162)

Here, the intention of the question was unclear and therefore it was not possible for the operator to select accurately the type of answer wanted. This example also illustrates that in open communication systems, ambiguity in the signal could be reduced not only by limiting the sign set but also by enabling a two way communication process. In this way the sender can either correct the receiver's response or the receiver may ask for the context to be more accurately specified, such as, using the earlier example, by asking "Which Janet?"

Even if the sender and receiver do not make errors in the selective encoding and decoding of messages, all communication signals are prey to disturbances or noise. This noise is added to the message as bogus, unwanted information, and this affects the receiver's potential for making accurate selections and is likely to increase the time that this takes. For example, when relevant information is buried in a mass of irrelevant information, the latter constitutes noise. Such a situation significantly contributed to causing the serious accident at Hixon level crossing for example, (Great Britain: Ministry of Transport, (9)) which resulted in 11 deaths and 45 injuries. The Ministry of Transport did not emphasise important information in its national publicity concerning the operation of the new automatic crossings. Neither did British Rail, responsible for local publicity, who produced a weighty document containing a mass of irrelevant information as far as the disparate organisations who received it were concerned.

Fuchs et al (10) comment on similar deficiencies in written emergency procedures; either commands were written as added cautions and notes instead of specific statements, or extraneous explanatory information was included. This is an example of the latter:

> "Following a period of approximately constant temperature, the primary coolant temperatures increase to well above the secondary saturation temperature, indicating the loss of heat sink by dryout. This is an important indication of the approach to inadequate core cooling. If the RCP's are off, cold leg temperature will initially increase faster than hot leg temperature, resulting in decreased core /\T. Use TR-0115 and TR-0125 for cold leg temperatures and TR-0111 and TR-0121 for hot leg temperatures. Using the recorders will show a trend for easier determination of temperature trends." (Sec.2, p.13).

The authors (10) recommend the following remedy:

> "Using appropriate temperature recorders (see table), determine hot leg and cold leg temperature trends. Go to step indicated by table."

[A table of temperatures was provided] (Sec.2, p.14)

In the previous case, the explanation of the system was irrelevant; the superiority of the remedied procedure should be evident.

When communications are unavoidably subject to noise and therefore the receiver is likely to make an uncorrectable and unidentifiable mistake, the introduction of redundancy into the message can be used. All redundancy is, in effect, addition and in its simplest form is plain repetition. Messages exhibit redundancy if they contain less information than they could by virtue of an excess of rules; by implication, messages could be shortened by removing redundancy. This must be distinguished from the concept of irrelevant information mentioned earlier, since a message sequence which exhibits redundancy enables one part of the message to be predicted from knowledge of another, e.g. "Mary .... lamb, its fleece .... snow." The system of specifying code letters in air traffic control or in police radio communications is an example of use of redundancy, e.g. "Nectar one four metro" for N14M. Similarly, the use of a whistle code accompanying the traffic control gestures of Italian policemen is also redundant.The term "redundancy" is therefore something of a misnomer whereas "irrelevant" clearly refers to information which is of no value in carrying out a particular task.

Besides noise, other factors affect transmission, for example the capacity of the communication channel(s). If channels are being used to capacity, additional signals will be lost or delayed until the channels are cleared. Busy telephone lines are a good example of a communication channel being blocked because of limited capacity. Alternatively, receiving several communications at once that exceed the processing capacity of the receiver can result in delay as response priority will need to be determined, and in some cases a complete failure to respond to certain messages will occur. Both these examples have occurred as contributory causes of accidents (e.g. Great Britain: Department of Transport, (11); Great Britain: Health and Safety Executive, (12)). Capacity problems may exist because resources are limited, or they may be exacerbated when the number of people in a communication network increases but the available channels of communication do not, or when the need for communication increases as can occur in emergency situations. Rules for communication also need to specify, therefore, not only <u>what</u> and <u>how</u> to communicate but also <u>to whom</u>. This point is elaborated in the following section.

<u>SPECIFIC COMMUNICATION PROBLEMS</u>

Although the use of an information processing model enables error prone points in the communication process to be identified, an examination of actual communication errors can be used to highlight specific weaknesses in a particular system. Communication errors are often difficult to identify because the consequences are generally not immediately observable, if at all. For this reason much of the evidence must be taken from cases where accidents have actually occurred and although this may bias conclusions it is, at present, the only reliable available source of data.

<u>What to communicate</u>

1 <u>Language set limited by lack of system knowledge</u>

In the explosion accident at Houghton Main Colliery, Yorkshire (Great Britain: Health and Safety Executive, (12)) an electrician recorded a fault in a ventilation fan which had been switched off because it had been sparking. He very correctly reported the defect on his report sheet but did not note the fact that the fan was sparking. Had the fan later been repaired, this omission would have been of little consequence. However, it was not, and the firedamp that subsequently built up in the mine was later ignited by sparks from the unrepaired fan when switched on a few days later. The electrician was solely concerned with electrical faults, and the set of responses associated with this role would appear not to have included consideration of the implications of sparking with regards safety.

2 Language set limited by expertise

The limitations imposed by lack of knowledge or lack of consideration of the safe operation of a system in the above example, is also amply reflected in expertise. It is not surprising that the influx of hundreds of experts on the occasion of the Three Mile Island Accident (President's Commission on the Accident at Three Mile Island, (13)) generated an equally large number of interpretations of the nature of the accident (Nelkin, (14)).

Expert testimony is not always what a situation requires. Prior to the 1966 Aberfan disaster, where a coal tip descended onto the village killing 116 children and 28 adults, the National Coal Board had quelled the fears of the local council by using an expert. They sent the Area Planning Engineer to a Town Planning Committee Meeting. Unfamiliar with the situation and unbriefed, he advanced a tier-tipping scheme without giving it proper consideration, but nonetheless presenting it with an air of authority. The borough accepted the persistent reassurance from NCB officials who were, after all, legally responsible and presumably expertly qualified (Bignell, (15)).

3 Ambiguous and inappropriate messages

Communications can be ambiguous or inappropriate. In the Sellafield incident, Standing Instructions, January 1983, regarding highly active plant wash tanks, required that a solvent float off procedure be carried out. However, Plant Washout Instructions, October, 1983, were annotated with a handwritten note which said "For this shut down it is proposed not to float off and recover solvent from HAPW's." Although ambiguous and confusing, this note was not actually the cause of highly radioactive solvent being ultimately discharged into the sea. According to the reports (4) (5) the reason appears to be related to inappropriate information recorded in the shift log book on 10th November concerning the contents of highly active plant wash tank B (HAPW B). The records of contents were as follows:

"ejections from HASW [highly active solvent wash] (am shift 8th Nov.)
"ejections from HASW washes" (am shift 9th Nov.)
"ex HASW washout" (am shift 10th Nov.)

This last entry, later amended, suggested that solvent had been floated off. This was not the case, unknown to the afternoon shift, and discharge of HAPW B contents to Sea Tanks was authorised.

In a railway incident where a train was found to have defective brakes, a message to the Power Controller was interpreted as suggesting that the train should be changed, if possible. Lack of knowledge on the part of the receiver about the state of the train and a failure on the part of the sender to unambiguously state the serious nature of the brake fault led to the train remaining in service (11).

The person writing the procedures for the use of safety missile pins on

RAF jets failed to take into account that Phantom jets might be a special case. In fact they were impossible to fly with the pins in place. The result was that the procedures were ignored, a Phantom jet was used in a training mission with live missiles and a Jaguar aircraft was subsequently shot down at a loss of about £7 million (The Times, (16); The Guardian, (17)).

4 Sender-receiver mismatch

When communications occur across systems boundaries, problems in relating the sender's knowledge to that of the receiver's can result in error, such as the provision of irrelevant or "foreign" information and/or the omission of relevant information or emphasis, e.g. as occurred in the Hixon accident (9) mentioned earlier.

How to Communicate

1 Means of communication not available

Although an operator may have information regarding a particular system state he may not actually be able to communicate this information because the means to do so are not available. An example is given by Hunns (18) concerning the use of a now outdated communication system between signalmen at either end of a tunnel. The system involved the use of two way communication between signalmen using needle telegraph, an automatic semaphore signal to train drivers, and a one way flag signalling system between signalman and driver in case of failure of the automatic system. Because the system was designed to prevent two trains being in the tunnel at once, it did not provide a means of communicating "two trains in tunnel." When this situation actually occurred, the subsequent misinterpretation of messages transferred between signalmen as a result of an inability to communicate the actual system state, resulted in a third train being allowed to enter the tunnel.

In the above example, communication about a particular system state was not possible. However, communication may be blocked because of limited resources. One example is of the chargehand fitter in the Queen Street station accident (11) who, because a telephone link was engaged, failed to contact the maintenance controller about the train's faulty brakes and subsequently allowed the train to remain in service. The maintenance controller would have put a one journey restriction on the locomotive had he received the call. As it was, he assumed the chargehand was still working on the locomotive and that no further action was required.

In the Phantom jet incident (16) (17) warnings that live missiles were being carried could not be provided. Both the red tape normally placed over the master switch when live missiles were being carried and the statutory yellow notices indicating "aircraft armed" were not available.

In the above examples personnel made assumptions about the system state. In all cases they were wrong.

2 Formal methods break down

The use of log books has frequently been a source of error. The Sellafield incident (4) (5) is a good example (see earlier description). This system not only relies on complete and accurate information being recorded but also on the necessity to do so being perceived by the sender and the necessity to actually read the message being perceived by the receiver. Logs seem to be used to transfer information between shifts or between groups with different functions. For example, train drivers may enter problems in a repair book for referral to maintenance departments, or operators may record notable incidents for subsequent inspection and analysis by management. Errors in this sort of record system are quite common, ranging from failures to make entries to loss of a record book. These errors result in reliance on informal communication systems such as passing on information by word of mouth or by notes (e.g. (12)), a system which can easily fail.

It may be that formalised means of communication come to be regarded as unnecessary by those who are familiar with using the system. In the Queen Street Railway accident (11) for example, fitters failed to acquire information from standing orders because they considered that learning from more senior fitters directly was a more efficient means of obtaining information regarding maintenance procedures. As a result standing orders relating to a new class of locomotives were not read, despite being made available in the library.

Who to communicate with

1 Interpersonal barriers

There is a great deal of evidence to show that communication barriers exist between people, not only because of differences in physical location, but also due to factors such as status or personality differences (e.g. Blau (19), Gaines, (20), Read (21)). Such problems exist in hierarchical organisational structures. Operators tend to ask their workmates for help rather than their supervisors for fear that this would reveal their incompetence. Downward communication flow in a hierarchy is less impeded and tends to be in terms of instructions or orders but is also reflected in the use of experts. However, upward communication is also important because those closest to the task are apt to have knowledge of facts and details unknown to superiors. The Aberfan disaster (15) is a good example of upward communication failure. At the time, NCB archives showed no record of similar previous tip slides. Also, warnings of sinkings by the chargehand at the Aberfan tip were largely ineffective. The downward process may also fail. Managers have been shown to be lacking in issuing sufficient safety warnings in some of the accidents mentioned.

2 Information handling problems

Another problem evident in many of the accidents already mentioned is that complex organisational structures frequently involve the transference of information between a large number of people or between systems. The larger the number of people involved, the longer the message takes to reach its destination and the more prone to distortion or loss of information it is likely to be. Turner (22), found that inter-organisational grouping results in information handling difficulties, frequently a contributory cause of major disasters. In addition, informed outsiders can be considered to be uninformed alarmists, a clear example of organisational exclusivity.

CONCLUSIONS

The use of an information processing model is not ideally representative of all the aspects of interpersonal communication. This is particularly so when a natural rather than artificial language forms the basis of the process. However, it does serve to draw attention to error sensitive areas in the process. Examples of errors drawn from real life situations demonstrate the need to consider a wide organisational context as well as the characteristics of senders and receivers who participate in the process, particularly their knowledge and perceptions of the system. Because this is such a poorly researched area, further conclusions are limited until more work can be carried out. In the meantime, it is hoped that those who have control over systems design and safety will make use of the evidence that is currently available. It is not only necessary to formalise the inter personal communication process, but also to ensure that such formalisations are not allowed to lapse. Also, by providing sufficient noise free transmission resources, where possible, particularly where abnormal system states are likely to occur, and by directing the flow of communication, communication structure weaknesses can be minimised.

Finally, it should be apparent that natural languages are a highly imperfect means of communication as far as system safety is concerned. Future research should perhaps concentrate more on designing artificial language systems which are not prone to the problems of the alternative open systems currently in use.

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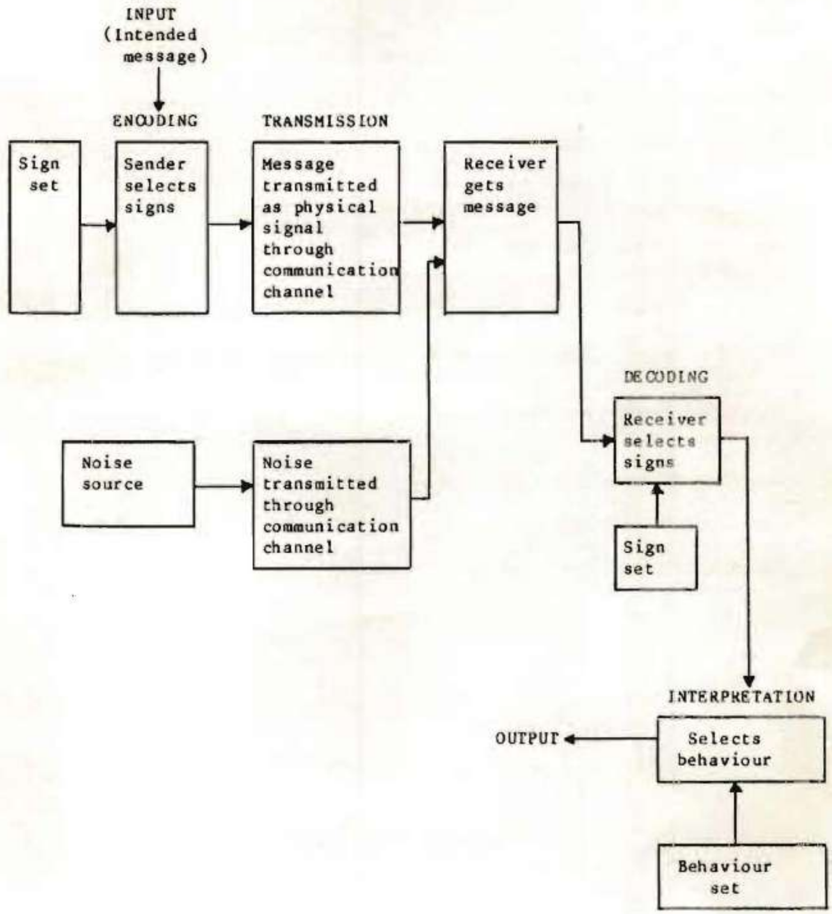

Figure 1 An information processing model of human communication.