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Impact of Information Theory on Future Communication Systems

by

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SUMMARY

Information theory provides us with two valuable quantities; a definition of quantity of information and the minimum cost of transmitting information. If proper recognition is taken of these factors many future military communication systems may be greatly simplified compared to present day systems and provide vastly improved communications at the same time. Recognition of these principles of information theory indicates that serious consideration must be given to the requirements for communication before communication facilities are provided. Too few cases, in the past, have received this attention. After deciding on the need for communication, information theory indicates the need for study of the form in which the information is transmitted. Much of present communication traffic conveys no information whatsoever. Applications of the above principles can result in major changes in our communication systems. The traffic load would be greatly reduced on operational or priority links with much of the present load relegated to more mundane methods of transmission. Many new specialized information links of the so-called proforma type will be introduced that accept information in non-redundant form. Information theory can have this impact on future communication systems but only if the military commanders of today decide that they want better communication systems more than they want communication systems to look like systems of the past.

The Impact of Information Theory

on

Future Communication Systems

The title of my talk today is 'The Impact of Information Theory on Future Communication Systems'. This title implies that Information Theory will have an impact on future communication systems but this is not necessarily so! Undoubtedly Information Theory can have a tremendous impact on the systems of the future, but whether it will or not, is more dependent on the decisions made by military planners and users, than on the potential of information theory to provide the answers necessary to give improved communications.

Many military communication systems could be greatly simplified, and at the same time, provide improved service if the lessons of Information Theory were followed. For example, serious consideration should be given to the requirements for communication facilities before the operational specification is completed. Too few cases in the past have received this attention. After deciding on the need for communication, a study should be made of the form in which information is transmitted. Application of this principle would result in major changes in our communication systems. The traffic load would be greatly reduced on operational or priority links with much of the present traffic relegated to more mundane methods of transmission. (I would venture to say that present day trans-Atlantic commercial air mail is often as fast as non-priority military radio.)

One of the results of applying information theory will be the introduction of many systems of the proforma type that accept information in non-redundant form. These systems, when properly designed, ensure that only information pertinent to the intended operational role is transmitted.

While these points as to quantity and form, are central to Information Theory, they have often been decided without regard to the principles of Information Theory. It is clear that there is a great need for cooperation between the military planner and the communications systems designer from the very inception of an operational role.

It is undoubtedly true that in many cases there has been excellent cooperation between various levels of planning staff in designing complete military systems but I would like to suggest that communications has seldom been given equal weight in planning with fire power or mobility.

I would like now to pass on to those aspects of Information Theory that can have most impact on future military communications.

First of all, I will describe some of the basic principles of information theory, giving some of their implications, and then I will describe a number of proforma systems that result from the application of these principles.

Information Theory provides us with two valuable quantities: a definition of quantity of information and the minimum cost of transmitting information.

The first of these points which are fundamental to information theory is that information has measure. Information is normally measured in units called bits. A selection of one of two equally probable messages is said to represent one bit of information. If there are four equally probable messages, any one of them can be selected by two choices and a selection is equal to two bits of information. If a source has a number of unequal possibilities, the information represented by the selection of one of these possibilities is equal to the number of equally probable choices necessary to select it.

This tells us that unexpected messages have the largest information content and that certainties have no information content.

Perhaps an example would better illustrate what is meant by quantity of information in bits. How much is 10, 20, 30 or 100 bits of information? Ten bits of information is enough to specify any one of 1024 messages. Twenty bits is sufficient to specify any one of 1,048,576 messages. Thirty bits can specify any one of 1,073,741,824 messages. One hundred bits can specify any one of approximately 10^{30} messages!

What do you find if you apply this to a normal telephone channel where 10,000 bits can be transmitted every second? How many messages can 10,000 bits specify? It is incomprehensible to the mind. A telephone channel could pass any possible message in every possible language by any possible human, dead, alive or yet to be born. How often can we afford to pay for such a capacity?

The second of the points I wish to make is given by the formula for channel capacity. The capacity of an information channel is given by the expression, c for capacity in bits per second equals bandwidth, W, in cycles per second times the logarithm to the base two of the signal power, P, plus the noise power, N, divided by the noise power, N.

The information that can be passed through a channel in a given time is given by

$$I = WT \log_2 \frac{P + N}{N}$$

This expression gives us what it costs at the very least to transmit information in terms of energy, bandwidth and time.

Because time, bandwidth, and energy are valuable articles which we do not wish to waste, serious consideration should be given to the decision as to what should be communicated. The question is, can you afford the energy, bandwidth, and time to communicate information of a given value. Reducing the information flow will save money and time and furthermore perhaps make it possible to communicate; for when you try to exceed the information capacity of a channel, the result may be no communication.

I have indicated how to measure information and what the minimum cost of transmitting information is but I have not said what I mean by a communication system. The next slide shows the various components of a communication system. This diagram also points to a common weakness in thinking about communication systems. Frequently only the part of the system to the right of the dotted line is thought of as being the communication system. The information source and receiver and the source encoder and decoder are an integral and most important part of any communication system. The source, whether man or machine, must be included in the design of communication systems. The source encoder is most important in the design of an efficient communication system for it reduces the output of the source to as pure information as conditions allow. In general, inputs to a communication system should be reduced to a non-redundant form and then encoded for optimum transmission through a communication channel. This is seldom done in practice.

For efficient design of a communication system, the planning of command and combat structure must include communications from the very beginning. It is even conceivable that in many cases combat systems should be designed to work without command and therefore without communications. This is in contrast with the ever increasing burdening demand for more and more telephone channels, not for more communications incidentally, but for more channels.

When communication systems are designed for specific purposes using the basic principles of information theory, systems of the proforma or list code type will often result. I will now describe several of these systems; some have been in existence for a long time and some are still to come into use. Finally I will demonstrate a simple special purpose proforma communication system which includes error detection and correction.

That illustrious but often frustrated American naval commander, John Paul Jones, introduced du Pavillon's flag hoist signal system to the USN during the War of Revolution; as in many other ventures, the gallant commander was often unsuccessful. Hoist his flags he might, but if his lieutenants wouldn't read them he could not succeed.

In the du Pavillon system one of 1600 different signals could be sent by hoisting two flags and a pennant. There were ten flags representing the numbers 0 to 9 and three long pennants representing 100, 200, and 300. 0-99 was represented by two flags. 100-399 was represented by two flags and a pennant. By raising the signals on different masts or yards the numbers could be extended to 1600. Each number represented a phrase, the key for which was contained in a signal book of 100 pages. Here we find the principles of information theory being applied long before information theory had been invented!

In 1950, Dr. Tuller presented the results of a study by a Special Committee of the Radio Technical Committee for Aeronautics of a transition period air traffic control communication system.

The next slide illustrates the information transmitted for control of the aircraft. The information capacity required for contact with 15 aircraft every five seconds was only 108 bits per second. Contrast this with the 10,000 bits capacity for voice communications.

Although the results of this study were presented in 1950, it is still not adapted for general aircraft use in 1960.

The US Federal Aviation Agency's experimental automatic communication system for air traffic control was described in 1958 at the 2nd National Symposium on Global Communication at St. Petersburg Beach, Florida. An example of a message for ground-to-air communications is shown in the next slide. It consists of a synchronization period, a label indicating one of 16 possible modes of operation, an aircraft address permitting over a million and a half separate aircraft addresses, a slot for acknowledging the previous message, one of 31 discrete messages, a clearance altitude capable of assignments to 100,000 ft., a spare message space for future additions, and a parity check. This total message consisting of 82 binary signals occupies only a tenth of a second. The plans given in 1958 called for the completion of engineering models before July, 1961.

Another example of a proforma communication system is the BASIC system which has been developed for the US Marine Corps! The message format is illustrated by the input signal box shown in the next slide. This system is for gathering tactical information in the field and transmitting in less than 3 1/2 seconds, for near instantaneous display on a battle display map like the one shown in the next slide.

To illustrate the operation of a simple proforma communication system, Mr. David Coll of the Communications Laboratory has constructed an experimental system capable of transmitting 512 different messages. The message number is selected by the positioning of nine on-off switches, representing nine binary decisions. The message represented by turning the first, the fifth and the ninth switches ON is now shown by the Input Display. The message is transmitted when I push a button and in less than a thousandth of a second the information is displayed at the receiver. In addition to the nine information bits, seven extra bits are transmitted to provide error detection and correction. If an odd number of errors occur on any one line the fourth light on this line will go on. If only one error occurs the intersection of the two error lights will permit correction of this error.

Proforma communication systems such as the ones I have described permit more efficient communication for special applications where the list of messages can be specified.

Application of the principles of information theory could result in many other changes in present day communication systems, changes which would result in more reliability, in simplification of equipment, and above all, in the reduction of communication capacity required. This would result, for example, in many cases in the use of coded data systems instead of voice.

The demand for radio communication facilities increases apparently without limit, and the current planned expenditures for future communications are staggering. If the simple facts that information has measre and that it costs to communicate are kept in mind in planning communication systems from beginning, it would be possible to meet our needs with greatly reduced expenditures.

Improving methods of transmitting information through a channel will increase our ability to communicate, but only marginally. The capacity of an information channel is no more than ten times greater than the rate at which present channels pass information. Greater improvements will only come through an assessment of the demand for communication and the quantity of information to be transmitted. By source coding, speech at 100 words per minute can be reduced to 15 bits of information per second, resulting in a reduction of 600 times in the capacity used for voice signals.

This afternoon, I have tried to give you some indication of how information theory can help guide the design of systems to satisfy communication needs, and what impact information theory can have on future communications systems. Whether or not it will have as much impact as it can, depends on the decisions that will be made by military commanders. I hope that these decisions will be made in cooperation between the scientist and the sailor, soldier or airman at an early enough stage of planning so that an adequate account can be taken of information theory in the design of communication systems of the future.

21 November, 1960