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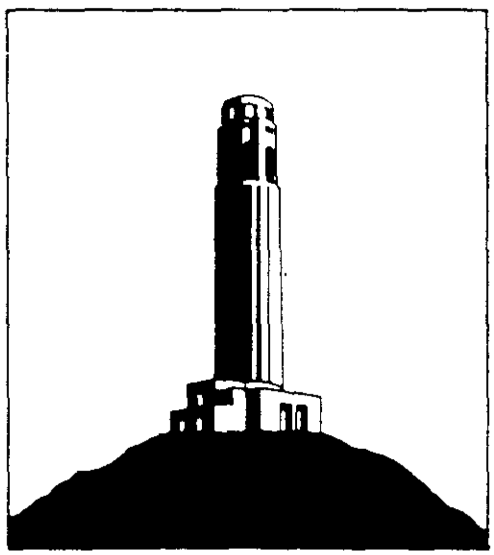

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SOME SOCIAL IMPLICATIONS OF THE MATHEMATICAL THEORY OF COMMUNICATION CHANNELS

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ABSTRACT

The empirical correlation of information input overload phenomena as developed by James G. Miller is reviewed to lay the basis for considering analogies between different levels of communication channels. Then the entropies of alphabets for discrete and continuous channels are discussed. Next the plausible relationships between the different abstract boundary conditions are explored, and the social systems examples are evaluated as a tentative test of the social analog of the mathematical theory of electrical communication channels. These three sets of boundary conditions lead to theories of income distribution, political rights (voting), and distribution of power by political groups in developing countries.

INTRODUCTION

Some of my ancestors were members of the Society of Friends in England during the time of George Fox (1624-1691), while others joined the Unitarian Church, which followed with some interruptions the leadership of Miguel Serveto (1511-1553).[1] Although I have always been interested in standing up for human freedom, I neither have as much courage as George Fox, who spent a large part of his life in and out of jails, nor as Miguel Serveto, who was burned at the stake. Following the sociological uncertainty principle, I have tried to maximize my observations and analysis of the social impact of technology and engineering theory without exceeding the bounds for which one gets ejected from the social system. Part of this strategy involves working in a large industry and discussing the social impact within church groups.

The study of the social impact of electrical communication theory has met with a number of obstacles. Since this is a technical paper, I shall not go into such details here. Information on these non-technical problems is available elsewhere.[2]

BEHAVIORAL SCIENCE AND INFORMATION THEORY

In 1954 I went to a conference at the Center for the Advanced Study of the Behavioral Sciences, Stanford. At the conference plans were formulated for a scientific society to help develop studies searching for isomorphic relationships of concepts, laws, and models in various fields of science. This organization is now known as the Society for General Systems Research, and became affiliated with Section L of the American Association for the Advancement of Science at the Berkeley meeting in 1954.

One of the leaders of the conference, Dr. James G. Miller, a psychiatrist, and director of the Mental Health Research Institute at University of Michigan, outlined some studies of output rate versus input rate for information passing through different levels of bio-social systems.[3] A set of curves from a later paper of his have been replotted on a set of similar curves for electrical communication channels in Fig. 1. I was impressed by the similarity of these curves to the curves of various electrical communication channels being discussed at conferences on Information Theory. The similarities in the curves of output versus input for different systems lead us to look for other similarities. For example, is there some analogy between the formulas for the entropy of signalling alphabets on telegraph lines to the entropy of some properties of social systems?

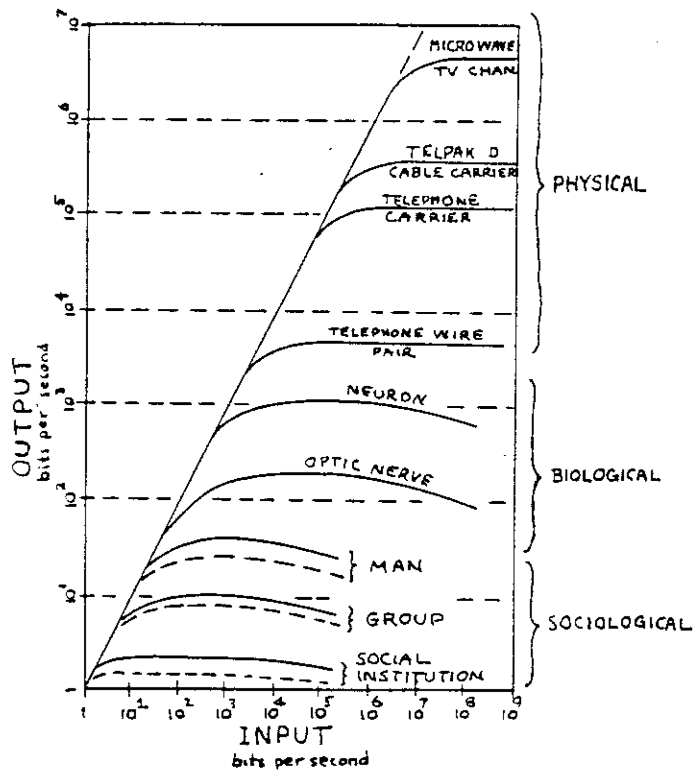

Fig. 1. Comparison of Information Input Overload Curves for Biological, Sociological and Physical Communication Channels

ENTROPY OF SIGNALLING ALPHABETS

Shannon has given us the formulae for the entropy of signals for a discrete channel and also for a continuous channel.[3]

$$H = -\sum_{i=1}^{i=N} p_i \log p_i$$

where p_i is the probability that message "i" is sent on the communication channel. Similarly for the continuous channel, we have:

$$H = -\int_{-\infty}^{+\infty} p(x) \ \log p(x) \ dx$$

where $p(x)\,\Delta x$ is the probability that the signal voltage is between $x - ½\Delta x$ and $x + ½\Delta x$. For maximum 'entropy', or 'negentropy', or 'communication entropy', depending upon whose terminology we use, we have for the discrete channel:

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$$p_i = 1/N \quad \text{for all } i,$$

and for the continuous channel for average power limited to σ^2:

$$p(x) = \left\{ 1/(2\pi)^{1/2} \right\} e^{-x^2/2\sigma^2}$$

Shannon and many others have applied these measures of entropy to sets of alphabets, sets of words in languages, distributions of signal voltages, etc. The next question is what properties of social systems can be treated in a manner similar to signalling alphabets? In 1963 and 1964, I experimented with using Shannon's discrete channel model to describe finite sets of discrete parameters, such as the set of freedoms people desire in a social system.[5] I also used the continuous channel model to represent the distribution of political power as a function of range of political philosophies.[6] Since then I have concluded that the boundary conditions are more fundamental for finding what types of social system properties can be represented.

BOUNDARY CONDITIONS FOR MAXIMUM NEGENTROPY

Fazlollah M. Reza summarizes the different boundary conditions for probability distributions that represent the principal different cases for maximizing entropy[7] in Fig. 2.

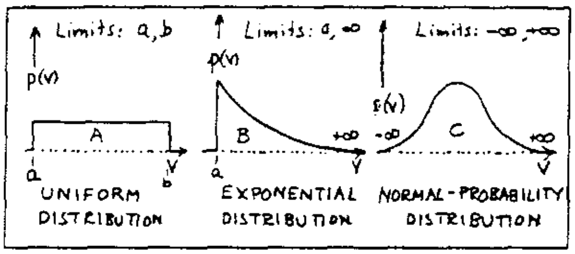

Fig. 2 Comparison of the Three Sets of Boundary Conditions for Maximizing Negentropy

What features of a sociological system might correspond to these three sets of boundary conditions? For the finite limits (a,b) it seems logical that the votes of people in a political system would have finite limits related to the finite number of people in a political state. Also, if we were to count the number of human freedoms people like to have, we would have a finite number of such freedoms to evaluate.

Next consider the boundary conditions (a,∞). The income distribution in a country might approximately meet these boundary conditions. Actually the boundary conditions for the income distribution at most would be (a,X), where X is a large number, but not really as large as infinity. For the boundary conditions (-∞,+∞), the scale of political philosophies is a candidate, except that they never reach infinity, but have the boundary conditions (-X,+Y), where -X represents the extreme left-wing political philosophy, or extreme communist views, and +Y represents the extreme right-wing conservative views or possibly anarchist views.

EXAMPLES FOR DIFFERENT BOUNDS

Case A: Finite Lower and Upper Bounds

If we take the formula for information or negentropy that was derived for telegraph message symbols and try applying it to a set of philosophies in a sociological system, we get some interesting results. Suppose we have n philosophical systems under consideration in a country. Substitute the probabilities that people believe in the different philosophical systems in place of the probabilities of occurrence of n symbols in the analysis of a telegraph system.

If there is no dominant philosophy, but everyone freely selects a philosophy and each philosophy turns out to have the same probability, then the negentropy of the social system in respect to philosophies would be:

$$H = -\log n$$

Suppose there are 100,000 people in a small city-state and that everyone has a separate philosophy, then the negentropy of the city-state in respect to philosophies is:

$$H = -\log_2 (1/100000) = 16.61$$

On the other hand, suppose the city-state is run by a dictator who requires every one to subscribe to one and only one official state philosophy. Even though it is probable that many people do not agree with the state philosophy, if we were to make a survey, they would probably give us poll results of 99.9% in favor of the state philosophy, because fear of the enforcers on the dictator's staff.

$$\begin{aligned} H &= -(0.999)\log_2(0.999) - (0.001)\log_2(0.001) \\ &= -(0.999)(-0.0014) - (0.001)(-9.9966) \\ &= 0.0014 + .0099 = 0.0113 \end{aligned}$$

These two examples give a negentropy of 16.61 for a completely free city-state where everyone has his own philosophy. In the one man controlled dictatorship the negentropy with respect to philosophy is only 0.0113 or practically zero. This tells us that the city-state with a negentropy of "16.61/philosophy" is probably more democratic. We have no measure of whether it is strong enough to withstand enemy attacks. This sample calculation is too oversimplified to help us analyze a real social system. However, it does give us a first approximation to applying information to the study of social systems.

A second approximation has already been computed, in this case a set of human freedoms relating to speech, religion, publication, sex, education, absence of job discrimination, home ownership, voting rights, trial by jury, and right to establish a small business or farm were treated like a set of telegraph messages such that the corresponding probabilities are substituted into the formula for negative entropy. The relative measure of democracy for six different hypothetical countries came out as shown in Figures 3A to 3F and in Figure 4.

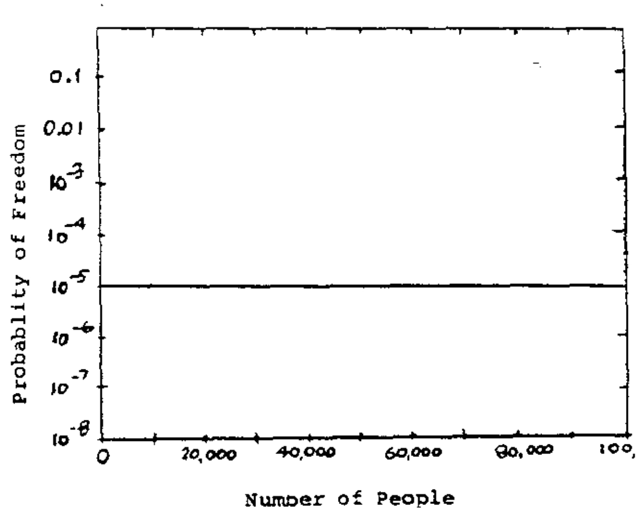

Fig. 3-A. Ideal Democracy

These calculations do not constitute a proof, but indicate that the hypothesis regarding the application of electrical communication theory equations to sociological systems can be tentatively used until contradictory examples are found. It is also necessary to know something about the other variables in the social system. To evaluate a sociological system may require knowledge of about 15 other variables in addition to negentropy. The assumptions as to the probabilities of the individual freedoms in the different countries, groups, and castes are tabulated in Table I. The details of the calculations are published in a separate report.[8]

TABLE I

Distributions of Freedoms Used in Sample Calculations

Country:	A	B	B	C	C	C
Group:		1	2	1	2	3
1	.1	.05	.110	.05	.1	.15
2	.1	.10	.11	.10	.1	.10
3	.1	.05	.11	.05	.1	.15
4	.1	.05	.10	.05	.1	.15
5	.1	.01	.11	.01	.1	.19
6	.1	.01	.11	.01	.1	.19
7	.1	.01	.11	.01	.1	.19
8	.1	.01	.10	.01	.1	.19
9	.1	.03	.10	.03	.1	.17
10	.1	.02	.112	.02	.1	.18

Country:	D	D	F	F
Group:	1	2	1	2
1	700	.01	8500	0.00
2	1	.01	8500	0
3	700	.01	8500	0
4	1400	.05	8500	0.1
5	700	.02	8500	0.01
6	700	.01	8500	0.01
7	700	.03	8500	0.02
8	700	.0	8500	0
9	0	.0	8500	0
10	1400	.02	8500	0.01

Country E:

Caste 1: $F_i = 0.34$ $G_1 = 0.034$

Castes 2 to 9: $F_i = 1.0$ $G_i = 0.10$

Caste 10: $F_i = 1.66$ $G_i = 0.166$

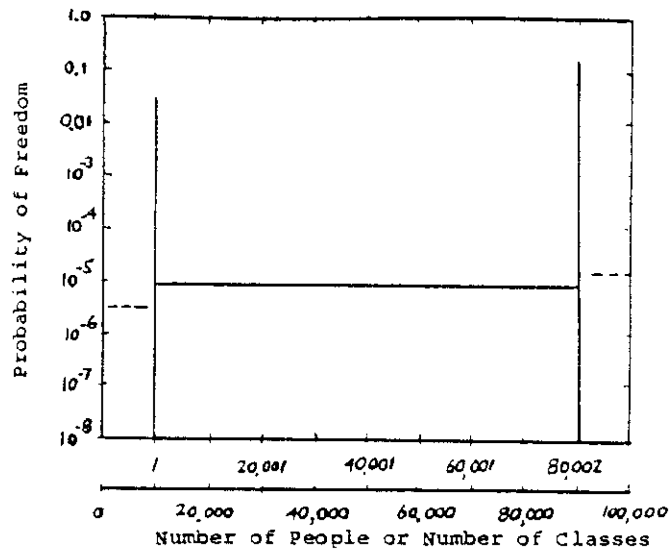

Fig. 3-C. Partial Democracy with Class Discrimination

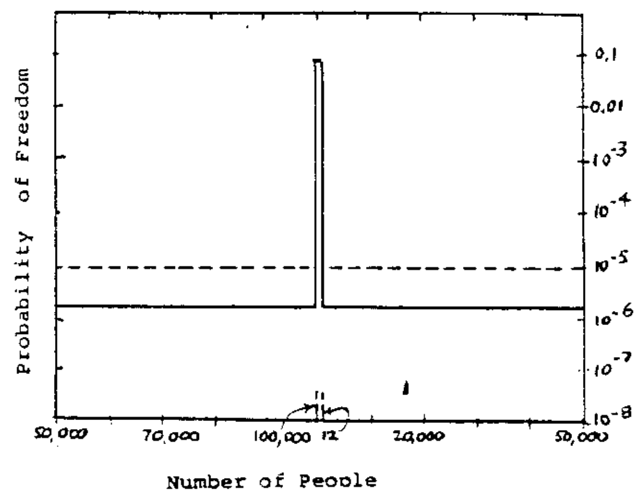

Fig. 3-D. Oligarchy of Twelve Person Committee

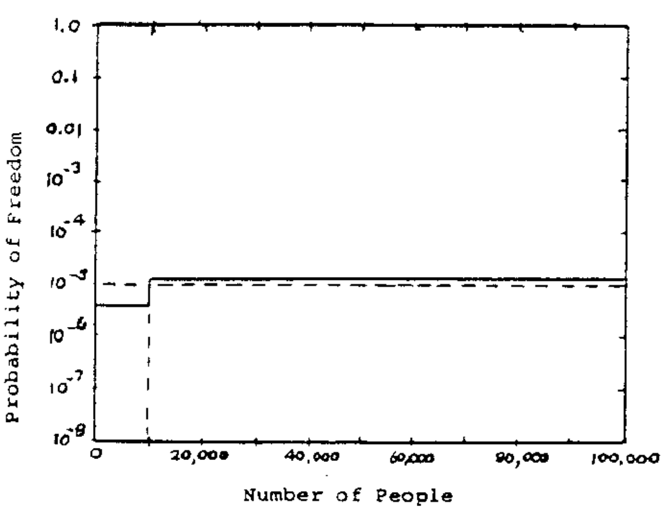

Fig. 3-B. Democracy with 10% Underprivileged On Individual Basis

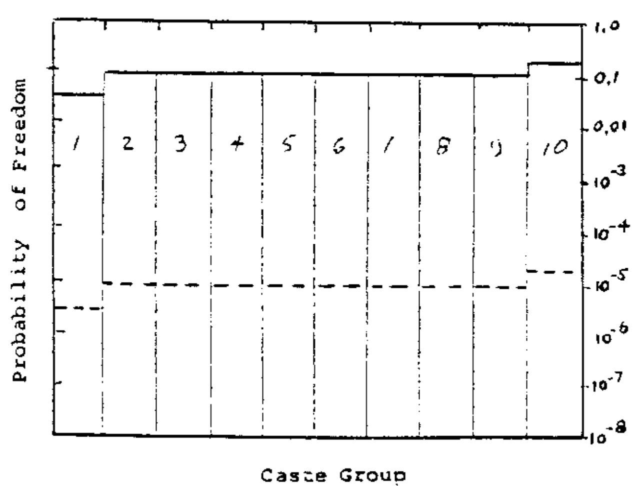

Fig. 3-E. Caste System

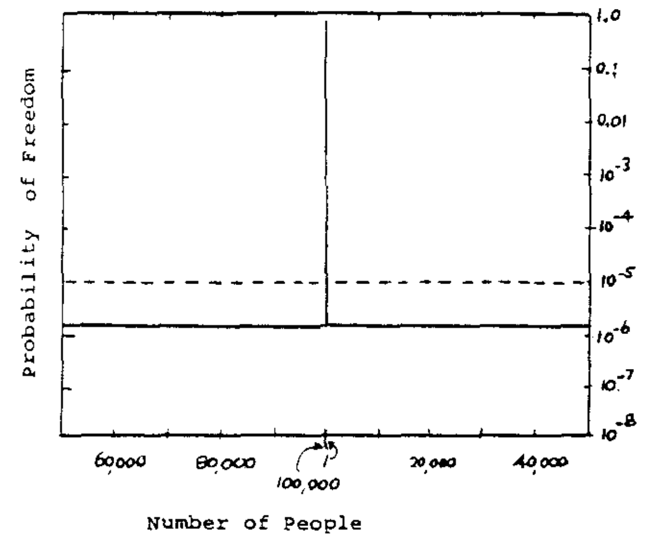

Fig. 3-F. One Man Dictatorship

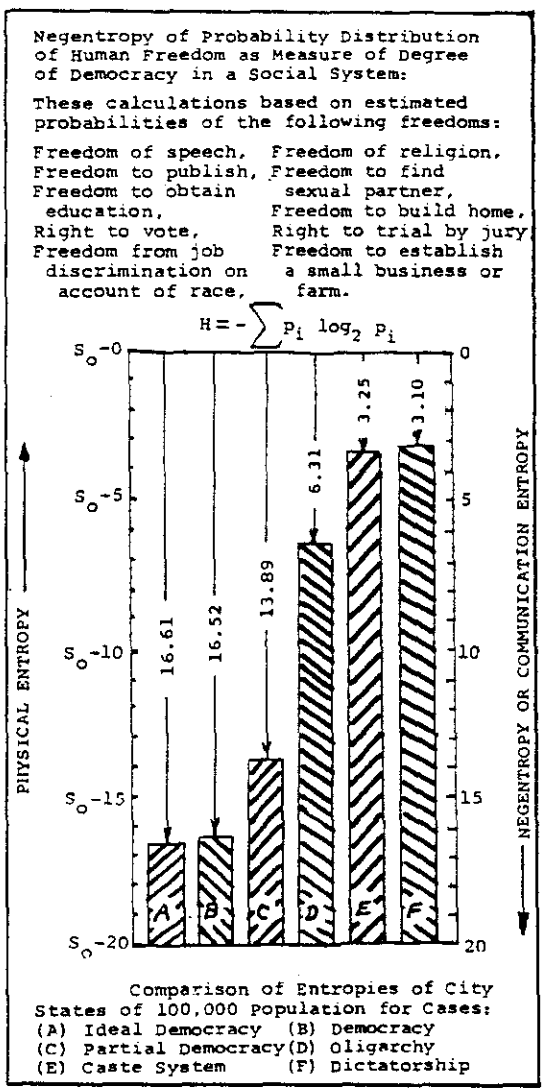

Fig. 4. List of Ten Human Freedoms and Resultant Values of Negentropy for Six Different Distributions of Human Freedoms

Case B: Finite Lower Bound and Infinite Upper Bound

For the finite lower bound with infinite upper bound the type of property of a social system that seems to fit is the distribution of income in a country or state. For the exponential distribution above some reference value A, and standard deviation σ, we have $t > A$, $P(t) = 1/\sigma \exp(-t/\sigma)$. The median, $m = 0.6931\ \sigma$. Sample data is given in Table II.

TABLE II MEAN INCOME AND WELFARE DATA FOR TWO STATES

State	Population	Welfare per Capita	Mean Income per Capita
District of Columbia	756,510	\$ 742	\$6,766
Mississippi	2,216,912	\$ 173	\$3,448
United States	208,230,000		\$4,918

For individual states we take the ideal income distribution from the principle of maximizing negentropy to give:

$$I(t) = W\ (1/\sigma)\ \exp(-t/\sigma)$$

where t is the income level in dollars per person, W is the average welfare payment per person on welfare, and σ is the standard deviation of the income distribution above the welfare level.

Sample curves are plotted in Fig. 5 for D.C. and Mississippi. To check whether these distributions come anywhere near practical values, we check the maximum incomes predicted on the basis of the population of the state or country. Setting P(t) = 1/population gives for Miss. \$29,168 per person maximum, for D.C. \$41,800 per person maximum, and for the U.S.A. \$74,049 maximum per person. To find the significance of these curves, we have to develop a way of testing the hypotheses and of investigating the criterion for a completeness theorem.

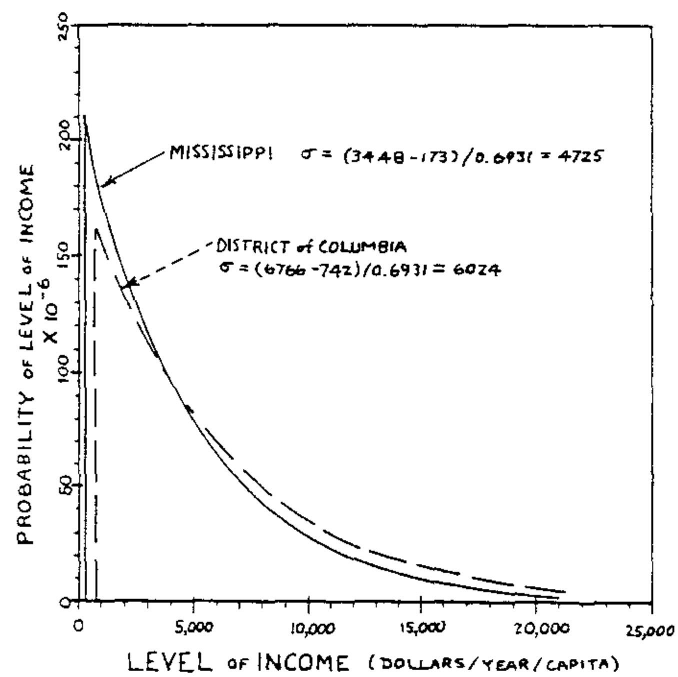

Fig. 5. Ideal Distribution of Income Levels for Two States Assuming 1973 Mean Income and 1973 Welfare Statistics

Case C: Upper and Lower Infinite Limits

Sample calculations for a set of hypothetical countries are made in reference (8). Some of the ideal curves for the hypothetical countries are plotted in Fig. 6. The area under the curves is proportional to the annual electric power production of the respective countries.

Curves corresponding to the constants tabulated in Table III are drawn in Fig. 6. The important feature of this model is that the "tails" on the probability distribution of political ideas must be preserved in order to maximize negentropy. This type of analysis should help the countries of the world move from policies of "power politics" toward a policy of "human development" in which two countries like Country C and Country D1 in Fig. 6 could change from a power struggle between their two ideologies to self and mutual criticism for not attaining the optimum political ideal distributions appropriate to their respective stages of economic development as measured grossly by their electric power production.

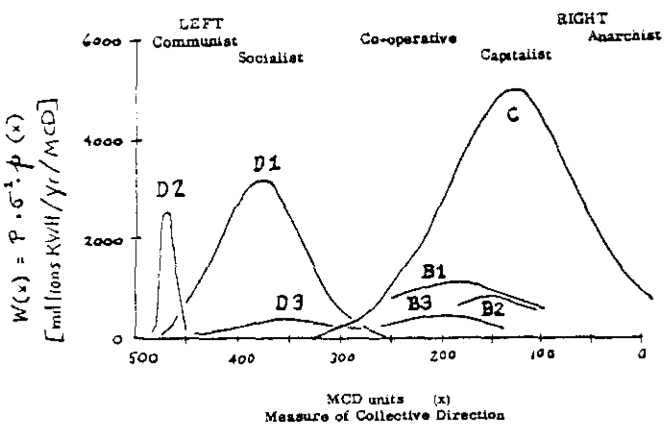

Fig. 6. Ideal Distribution of Power Versus Political Ideas for a Set of Countries

METHODOLOGY AND TESTING OF HYPOTHESES

The method used in applying concepts of electrical communication theory to sociological systems is the use of a "thematic hypothesis" in the sense defined by the historian of science and physicist, Dr. Gerald Holton.[9] Since it is not possible to develop a completeness theorem for the application of mathematical models to social systems, a series of quasi-completeness theorems have been proposed in another paper elsewhere.[10]

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(10) *CTCM.* Vol. III, No. 3.

TABLE III PARAMETERS OF A SET OF COUNTRIES BASED ON 1961-1964 DATA

Country	Measure of Collective Direction MCD	Population [millions]	Electric Power Prod. [millions K.W.H./yr]	Elec. Pwr. Per Capita σ2 [KWH/cap/yr]	Std. Dev. [σ]	People per MCD unit [thousands]	Country
B1	200	50	137,000	2750	52.5	324	United Kingdom
B2	150	45	72,000	1600	40	382	France
B3	200	17	114,000	6700	81.8	70.6	Canada
B4	100	52	116,000	2350	48.5	364	West Germany
B5	263	92	115,000	1250	35.4	882	Japan
B6	200	7	34,000	4900	70	34	Sweden
C	125	177	840,000	4750	69	870	U.S.A.
D1	325	210	292,000	1390	37.3	1,920	U.S.S.R.
D2	463	720	55,000	76	8.7	28,200	People's Republic of China
D3	350	16	40,000	2500	50	272	German Democratic Republic
D4	375	29	29,000	1000	31.6	313	Poland
E1	225	402	20,000	50	7.1	19,400	India