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Entropy in the Industrial Cybernetic System

The emergence of cybernetics — as a theory of optimal actions and a crucial moment in the development of human practice, knowledge and scientific theories — opens up unpredictible prospects in the process of control over natural and social forces.

Cybernetics has appropriated and adopted basic concepts of human knowledge, among which entropy holds a prominent place.

I. GENERALS

In contemporary society the discontinuous flow industry is one of the most dynamic branches, having the most complex economic connections and also a wide diversity in the assortment of production. These peculiarities viewed through the modern concepts about the industrial organization and management, provide conditions for the existence of a high entropy in the systems belonging to the branch. That is why this survey is meant to state a viewpoint on the part entropy plays in the systems belonging to the discontinuous flow industry, viewpoint which, in the author's opinion, can be extended to any industrial cybernetic system.

From the very beginning we take as granted the principle according to which the cybernetic concepts extended to economy allow the production units, the economic branches or economy on the whole to be considered cybernetic systems.

By definition, we consider that an economic cybernetic system is an aggregate of elements in interaction, including people, objects of labour and means of labour, where the manipulation, processing and control of materials, information, energy and man's actions aim at achieving a program esta-

blished in advance and determined by a management effort based on the principle of feedback[1]).

In this respect we can give the following details:

1. *The Industrial Enterprise defined as a Cybernetic System.*

Observing the fundamental characteristic of the cybernetic systems, the systems in economy can be decomposed in sub-systems mutually transmitting activities and information to each other, influencing one another and tending to carry out a self-regulating process. As such, in economy, the work place can be regarded as the simplest system (the irreducible system) where the first organic fusion comprising the three fundamental elements of production (labour, means of labour and objects of labour) is achieved. The irreducible economic cybernetic system can best point out, among other things, the distinction to be made between the performance and management functions that are first of all meant to carry out a certain development program of the respective system[2]).

Extending the division of the sub-system functions into the two categories, to the complex systems (reducible) we can consider that a set of activities corresponds to each function according to this relation:

$$\mathcal{S} = \mathcal{J} \sqcup \mathcal{E}$$

where $\sqcup$ = the sum of two structures;

$\mathcal{S}$ = the structure of all the activities of the system

$\mathcal{J}$ = the sub-structure of the adjustment activities $[\langle I\rangle \mid \langle \rho\rangle] \sqsubset \mathcal{S}$

$\mathcal{E}$ = the sub-structure of the performance activities $[\langle E\rangle \mid \langle \rho\rangle] \sqsubset \mathcal{S}$

ρ = adjustment operator

$\langle \rho\rangle$ = the set of the adjusting operators.

The adjusting sub-structure $\mathcal{J}$ contains activities of the following type:

internal $\rightarrow$ internal

external $\rightarrow$ internal

According to the performance type, the adjustment sub-structure refers to the inner character of sub-structure $\mathcal{J}$;

The performance sub-structure $\mathcal{E}$ contains activities of the type:

internal $\rightarrow$ internal

internal $\dashrightarrow$ external

According to the performance types, the adjustment sub-structure refers to the efficiency character of structure $\mathcal{E}$, the internal results referring to the operation proper.

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[1]) This definition is given in an extended form in: Bîrlea S., Homoş T. and Costoiu S. *Unele consideraţii asupra modelării cibernetice în industria construcţiilor de maşini*, "Buletinul Institutului Politehnic Bucureşti", No. 8, 1969.

[2]) An explanation of these functions is given in: Bîrlea S., *Concepte cibernetice aplicate la conducerea şi organizarea industrială*, "Studii şi cercetări de calcul economic şi cibernetică economică", No. 5, 1969.

NOTE

We shall consider the following definitions to be accepted:

1. Operations (structural calculus)

$$\mathcal{O} = [\langle S \rangle \mid \langle 0 \rangle]$$

where S = a set (part)

$\langle S \rangle$ = set of parts S or the aggregate of sets S of structure $\mathcal{O}$; it is written $S \in \langle S \rangle$

0 = operator

$\langle 0 \rangle$ = the aggregate of operators of structure $\mathcal{O}$; it is written $0 \in \langle 0 \rangle$

2. Ordering of structures

$$\mathcal{O}' \sqsubset \mathcal{O}''$$

($\sqsubset$ should not be mixed up with $\subset$, which stands for set inclusion or set ordering)

$$\mathcal{O}' \sqsubset \mathcal{O}'' \begin{cases} \langle S' \rangle \sqsubset \langle S'' \rangle \\ \langle 0' \rangle \sqsubset \langle 0'' \rangle \end{cases}$$

where S' = an element whatever of aggregate of sets $\langle S' \rangle$

ditto O' = an operator of aggregate of operations $\langle 0' \rangle$

We say that $\mathcal{O}''$ is the extension structure of $\mathcal{O}'$ or $\mathcal{O}'$ is a substrucure of $\mathcal{O}''$.

Remark.

We may write the set of sets, or aggregate $\langle \mathcal{O} \rangle$ also

$$\langle S \rangle = \{A, B, C, \ldots, S, \ldots\}$$

where the aggregate sets are described.

3. Sum of structures.

$$\mathcal{O} = \mathcal{O}' \sqsubset \mathcal{O}''$$

($\bigcup$ should not be mixed up with the union of sets)

$$\mathcal{O}' \bigcup \mathcal{O}'' = [\langle S' \rangle \bigcup \langle S'' \mid \langle 0' \rangle \bigcup \langle 0'' \rangle]$$

consequently

$$\langle S \rangle = \langle S' \rangle \bigcup \langle S'' \rangle$$

and

$$\langle 0 \rangle = \langle 0' \rangle \bigcup \langle 0'' \rangle$$

4. Structure intersection

$$\mathcal{O} = \mathcal{O}' \bigcap \mathcal{O}''$$

$$S' \bigcap S'' = [\langle S' \rangle \bigcap \langle S'' \rangle \mid \langle 0' \rangle \bigcap \langle 0'' \rangle]$$

consequently

$$\langle S \rangle = \langle S' \rangle \bigcap \langle S'' \rangle$$

$$\langle 0 \rangle = \langle 0' \rangle \bigcap \langle 0'' \rangle$$

The adjustment structure $\mathcal{G}$ of structure $\mathcal{O}$ is substructure

$$\mathcal{G} = \rho(\mathcal{O})$$

defined thus:

$$\mathcal{G} = [\langle \rho S \rangle \mid \langle \rho 0 \rangle]$$

where

$$\langle \rho S \rangle = \rho \langle S \rangle ;$$

similarly

$$\langle \rho 0 \rangle = \rho \langle 0 \rangle$$

It is obvious that we can find value $H(\mathcal{O})$ only if we are able to know the entropies of irreducible (independent) sub-systems, that is of the work places.

With this in view, we must find out

$$H(\mathcal{O}_\alpha) = H(\mathcal{O}'_\alpha) + H(\mathcal{O}''_\alpha) + H(\mathcal{O}'''_\alpha)$$

where

$\mathcal{O}'_\alpha$ = sub-system manpower

$\mathcal{O}''_\alpha$ = sub-system means of labour

$\mathcal{O}'''_\alpha$ = sub-system objects of labour

or

$$H(\mathcal{O}_\alpha) = \sum_{k=1}^{k=m_\alpha} p_{k_\alpha} \log \frac{1}{p_{k_\alpha}}$$

p_{k_α} = relative probability as against the action of the component elements of sub-system $\mathcal{O}_\alpha$.

These considerations allow us to explain that a certain cybernetic system $\mathcal{X}$ can be considered at moment t_0 be a structure defined as follows:

Sets A_α of structure $\mathcal{X} = \mathcal{X}(t_0)$ are sets of objects in the work process, sets of numbers which represent the amounts of materials and prices, which are associated in different ways to the objects of the work process; consequently, they are sets of adjustment activities.

The operations associated to structure $\mathcal{X}$ are fundamental operations relating to the sets of objects (consequently, of numbers) current in the set theory and in the function theory (union, intersection, product, set of parts, different applications).

The symbolic expression of the structure of process $\mathcal{X}$ is then

$$X = [\{A_1, A_2, ..., A_n\} \mid \{\cup, \cap X, \mathcal{P}, f, ...\}]$$

where

$$\{A_1, A_2, ..., A_n\} = \langle A \rangle$$

is the set or the aggregate of sets A_α.

If A_1 stands for a set of numbers X_{ij}, then $X_{ij} \geqslant 0$.

The conclusion to be drawn from these first considerations is that from the cybernetic point of view the presence of some great complex but finite structures (as i, j may have very high values) also signifies the existence of a high degree indetermination.

Hence the first hypothesis which is the basis of this survey: that the cybernetic industrial systems are systems tending to turn low entropy into high entropy, that is into increasing entropy [1]).

2. *The Efficiency Function of the Structure of Activities*

As we have seen, in structure $\mathscr{X}$ we particularly discern a sub-structure $\mathscr{A} \sqsubset \mathscr{X}$ which is a numerical sub-structure of the activities in system $\mathscr{X}$ representing the numerical sets:

$$\langle A_\alpha \rangle = \{A_1, A_2, A_3, ..., A_m\}$$

The numerical sub-structure of the activities in system $\mathscr{X}$ is decomposed in its turn into two numerical adjustment and performance sub-structures

$$\langle I \rangle = \{I_1, I_2, ..., I_m, ...\}$$
$$\langle E \rangle = \{E_1, E_2, ..., E_m, ...\}$$

Analyzing these definitions we conclude that a function $\varphi(E)$ relating to sub-structure $\mathscr{E}$ is an efficiency function if it shows how the system is reacting in the adjustment activity; it also shows the relation between adjustment and efficiency.

As is known, the efficiency functions in economy are of the form:

$$\psi = \psi(n_\alpha, v_\beta, c_\gamma, \tau)$$

where $N =$ the set of objects produced $n_\alpha \in N$

$V =$ the set of variables indicating the relative investment for the products in N, $v_\beta \in V$;

$C =$ the set of variables indicating the relative costs for the products in N, $c_\gamma \in C$;

$\tau =$ the recovering time of investment in V.

From the point of view of the efficiency, the operation of the industrial enterprise, similar to that of a cybernetic system, brings in, as one of the foremost objectives for production and labour organization, the ensuring of all necessary conditions in order that the production shall be carried out rhythmically for ever so long periods of time. The most favourable case will be obtained if the period when the unit works undisturbedly is longer or at least equal to the recovering time of investment. This assumes the existence of a permanent compatibility between the real possibilities of the pro-

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[1]) Several ways of interpreting the concepts of "low entropy" and "high entropy" are described in: Demetrescu, M. C., *Entropy, Information and Control in Economy*, "Economic Computation and Economic Cybernetics Studies and Research", No. 1, 1970.

ductive unit and the quantity of products that is to be programmed during the respective time period. The compatibility we have in view takes into account, as an essential element, the possibility of using the feedback method during the whole work process.

In the last analysis such a conception implies the observance of the following main condition:

$$KC_p \geqslant N$$

where

K = index of utilization of production capacity

C_p = production capacity

N = achieved production

τ = period of reference

3. *The Development of the Enterprise as a Cybernetic System*

As one can see, the checking of the correlation capacity — production suggests the possibility of an optimum control in a work process when:

$$f(K, C_p) = \text{maximum};$$

in this case the achieved purpose is

$$\sum_{\alpha=1}^{\alpha=m} N_\alpha = \text{maximum}$$

where N_α = partial productions.

However, we must remark that, in fact, the problem is even more complicated. From the economic point of view this solution holds only if the increase of production is achieved at the same time with a costs minimization per unit of product. This consequently implies the concomitant observance of this condition:

$$\frac{V}{\sum_{\alpha=1}^{\alpha=m} N_\alpha} = \text{minimum}$$

where V = the amount of all production costs.

Taking into account these synthetic expressions of the enterprise activity, on the basis of the general theory of modelling we can build up different mathematical models which can characterize numerous concrete aspects of the economic and production functions of the enterprise regarded as a cybernetic system. The fin ing of a mathematical model including all the sides of the processes taking place in an enterprise is a particularly complex problem whose investigation is still at the beginning.

II. ENTROPY OF AN INDUSTRIAL CYBERNETIC SYSTEM

1. *Entropy of Industrial Irreducible Systems*

The industrial cybernetic systems can be considered, from the mathematical point of view, as being heterogeneous structures of the form:

$$\mathcal{S} = [\{X, Y\} | \{f, \varphi, ..., \psi\}]$$

where

$$X = \{x_1, x_2, ..., x_m\}$$

is the aggregate sub-structure of the input signals;

$$Y = \{y_1, y_2, ..., y_n\}$$

is the aggregate sub-structure of the output signals;

$$\Phi = \{f, \varphi, ..., \psi\}$$

is the sub-structure aggregate of the transferring operators.

As such, the entropic state of the system cannot be defined unless the totality of the elements in the respective structure is taken into account [1]).

Indeed, we shall consider the following definitions to be accepted:

— message = the definite form through which the objective reality is reflected;

— information = the amount of symbols enabling the description and transmission, through a material carrier, of the structural qualities of a system, and

— entropy = the extent of the indetermination degree of a system, estimated by measuring the quantities of information achieved by the respective system.

On this basis we reach the conclusion that an economic cybernetic system must have an operation structure which essentially consists of adjustment, control, production, circulation, technical and informational activities.

As in the economic practice the quantity of information achieved by any system is very large, we must, in fact, operate with approximate systems. The best approximation, in a functional way, is given by the systems in which the input signals are scale functions and also A stands for scale operators.

This approach may be regarded as a possible way of practically solving the problems resulted from the numerical solutions supplied by the real phenomena prediction.

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The scale functions and operators can be quickly and directly calculated by means of integral and serial transformations, e.g. the Laplace integral unilateral operator, the final solutions becoming thus instantly obvious.

The evolution degree of the system is translated, for instance, by the functional:

$$f(\mathcal{S}) = \frac{||A(t_k) - A(t_{k-1})||}{t_k - t_{k-1}}$$

where $f(\mathcal{S})$ is an efficiency function of the system

$$\mathcal{S} = [\{X,\ Y\}\,|\,\{A(t)\}]$$

Similarly

$$f(\mathcal{S}/\mathcal{S}_0) = \frac{||A(\mathcal{S}) \cdot x(t)||}{||A(\mathcal{S}_0) \cdot x(t)||}$$

$$x(t) \in X = X(\mathcal{S}), \quad x(t) \in X = X(\mathcal{S}_0)$$

$$\left.\begin{array}{l} A(\mathcal{S}) \cdot x(t) \in Y(\mathcal{S}) \\ A(\mathcal{S}_0) \cdot x(t) \in Y(\mathcal{S}_0) \end{array}\right\} \quad t \in (t, +\infty)$$

where $\mathcal{S}_0$ is a particular system employed as reference. Operator $A(\mathcal{S})$ is always an operator whatever of system $\mathcal{S}$. The union in any — but definite — way of the cybernetic systems $\mathcal{S}_1$, $\mathcal{S}_2$, $\mathcal{S}_n$ ... with A_1, A_2, ..., A_n as transfer operators, results in a system where $A = \mathcal{S}(A_1, A_2, ..., A_n)$ works as a correspondent performance function of transfer.

As previously shown, the irreducible cybernetic system in industry is the work place. Any work place whatever can be mathematically symbolized as follows:

$$\mathcal{S} = [\{X,\ Y\}\,|\,\{A\}]$$

where

$x \in X$ stands for the object of labour before the transformation

$y \in Y$ stands for the object of labour after the transformation

$A = A_1, + A_2 + A_3$

where

A_1 — stands for the manpower operator, A_2 — for the means of labour operator, and A_3 — for the object of labour operator.

In view of the above, the irreducible industrial cybernetic system (the work place) can still be decomposed in 3 sub-systems:

— the sub-system manpower

— the sub-system means of labour — machine

— the sub-system object of labour — raw materials, parts to be worked.

The sub-system man is obviously an independent one among the three considered; the others are temporal systems whatever (the machine may

be working for a while without actual production; the objects of labour are subject to a change of their technical and functional structure in time, etc), and they may be just as well regarded, for short intervals, as atemporal systems, $A \pm$ constant or $A =$ constant, [1]) respectively.

On the account of the above mentioned characteristics, the two subsystems may mathematically speaking be looked upon as sub-systems with finite entropy, positive or zero, dependent on the evolution degree of the labour process. If, for instance, there is a work place where the working is done manually, the normal course of the process depends but on the implication of manpower, which may, from the cybernetic point of view, bring about a big rise of the entropy level within the system.

It is particularly noteworthy that in these cases, the entropy of the irreducible cybernetic system appears mainly as a result of the variation in the probability of action of the human element. It is therefore determined also by the training level of the latter, as well as the complexity of the work done.

That is why, in managing the system, it should be taken into account that the input signals will be turned into final results, chiefly depending on the labour power, which ultimately represents the decisive factor in the occurrence of self-adjustment phenomena with the cybernetic systems.

In case the mechanization and automation of the means of labour is carried into effect in the work place, then the entropy of the irreducible cybernetic system is modified, generally getting to depend on the technological level (the technical composition of entropy increases).

From this point of view, under complex automation, when the manpower interference is limited to a simple knob pressing or to simple operations, the entropy of the irreducible system becomes ever more a "technical" one, springing up from science and technology.

In so far as the technical means available become more adequate, the chief concern of the production organizer should therefore be the preservations of the previously established level of the technical composition of entropy, since the human composition plays an ever lesser part in production.

2. *Entropy of Compound Cybernetic Systems*

As commonly known, the industrial cybernetic systems are made up of unions of irreducible cybernetic systems. Consequently, the larger the union, the higher the increase of entropy of the given system.

In order to achieve a most efficient control over such cybernetic industrial systems, it should be reached a direct correlation between the control and adjustment activities, on the one hand, and the amount of entropy therein.

On the whole, the better organized a system, the lower the entropy level, established on the scale of the entire system.

That implies the ascertainment and knowledge at any time of the quantity of information comprised within the system.

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The entropy of a system whatever $\mathcal{S}$ is a mark for the adjustment of the system, which takes into account the variation of information related to $\mathcal{S}$.

The entropy of $\mathcal{S}$ is the functional

$$H(\mathcal{S}) = \sum_{k=1}^{k=n} p_k \log \frac{1}{p_k}$$

for a finite number of states of

$$\mathcal{S},\ \mathcal{S}(t_k),\quad k = 1, 2, ..., n$$

with P_k probabilities.

If there is a continuous infinite number of states for $\mathcal{S}$, $\mathcal{S}(t)$

$$\alpha \leqslant t \leqslant \beta,\quad t \in [\alpha, \beta]$$

t being a real temporal parameter, then the entropy of $\mathcal{S}$ is

$$H(\mathcal{S}) = \int_{t=\alpha}^{t=\beta} p(t) \log \frac{1}{p(t)}\, dt$$

$p(t)$ being evidently the probability of state $\mathcal{S}(t)$.

Similarly, we can define entropy $H(\mathcal{S})$ of the structure by using the Lebeasgue measure and integral.

With respect to a cybernetic industrial system consisting of irreducible, independent sub-systems (workshops, departments, enterprises a.s.o.)

$$\mathcal{S} = \mathcal{S}_1 \sqcup \mathcal{S}_2 \sqcup ... \sqcup \mathcal{S}_n$$

entropy will be:

$$H(\mathcal{S}) = H(\mathcal{S}_1) + H(\mathcal{S}_2) + ... + H(\mathcal{S}_n)$$

or

$$H\left(\bigsqcup_{\alpha=1}^{\alpha=n} \mathcal{S}_\alpha\right) = \sum_{\alpha=1}^{\alpha=n} H(\mathcal{S}_\alpha).$$

III. RELATION BETWEEN ENTROPY AND MODELLING OF THE PRODUCTION PROCESS IN THE CYBERNETIC INDUSTRIAL SYSTEM

In the discontinous flow industries, one of the essential peculiarites of products is this: they are achieved by the aggregation of several sub-assemblies, which in their turn are made up by a larger or smaller number of pieces, which have to keep their form, sizes and internal structure during the whole work period of the finished product. The production process in these branches is, in the main, the sum total of individual performances of each product.

Likewise, each individual process is in its turn a sum of processes, specific to each work place which makes up the fabrication flow.

Consequently, the entropy of such a system is the sum total of partial systems entropies.

Taking into account that a modern finished product in the discontinuous flow industry contains 10—20,000 different pieces which are made at an average number of 30—40 work places, we can realize the extent of the entropy of such a system.

But it is also possible to achieve a lower entropy, even in the case of a large system, in case that all the component sub-systems contain low entropies, because, if $H(\mathcal{S}) = \sum_{\alpha=1}^{\alpha=n} H(\mathcal{S}_\alpha)$ and $H(\mathcal{S}_\alpha)$ has a low entropy, then also $H(\mathcal{S})$ has a low entropy.

At the same time it follows that if a single subsystem $\mathcal{S}_\alpha$ possesses a high entropy, then the whole system increases its entropy.

For this reason the main problem in production and labour organization is to find efficient solutions in order to diminish the system entropy. This can be achieved through two principal ways:

— Statement of some suitable distributions of sub-systems, so that their whole structure as component parts of the aggregate cybernetic industrial system may contain a minimal entropy.

— Reduction of the existing entropy in each work place.

From a general survey of the cybernetic economic systems it follows that the adoption of the first way can be dealt with in simplified assumptions by building up some mathematical models which have to take into account the peculiar situation of system S.

In connection with the second way, the decrease of entropy in each work place — as shown in the studies on up-to-date management and organization methods in discontinuous flow industries — can be obtained in the main through:

a. Reduction of entropy which the manpower introduces in the process, *performance combination*, in order to get the most possibly variated scale of operations with indirect interference of manpower. The highest degree reached in this direction is represented in our opinion by the digital control machine-tools.

b. The interference to the greatest possible extent of manpower in the production process, based on a maximum performance development of the process, simultaneously with the restriction of the variation limits of entropy in each work place. A maximum improvement in this respect is reflected in our opinion, in passing to a conveyor manufacture, namely the introduction of a compulsory manufacturing rate.

The general conclusion resulting from the previous assertions is that there is a direct relation between the building up of mathematical models describing the phenomena in industry and the systems entropy. The mathematical models should aim at covering a quantity of information sufficient to reduce the system entropy to a minimum.

The attempt to exceed this limit introduces an even higher degree of indetermination in the system, and thus complicates the possibility of knowing the objective reality.

In both situations, the organizer has to do his best in order that the mutual interferences of the systems can develop within certain limits, so that the whole operation of the economic system shall be highly efficient.

From the cybernetic point of view, we have permanently to do with an aggregate of black boxes, whose connection may bring forth the best possible development.

IV. THE USE OF ENTROPY IN MAKING DECISIONS OF INDUSTRIAL ORGANIZATION

1. *The relation entropy — manufacturing system.*

The presence of a certain level of entropy makes that the industrial processes have always a probabilistic development, and their prediction always contains a certain factor of error. Obviously, there is a close relationship between the size of this factor and system entropy [1]).

Consequently, the prediction contains a minimal error only in the cybernetic — industrial systems with low entropy, operating at a high degree of stability. The solutions to this problem are — as it has been proved — different and even opposite, namely: either the diminution of direct interference of human force in the manufacturing process on account of the increase of technological entropy, weight, or the increase of direct human activity under a maximum performance distribution, so that entropy which the human factor introduces in the system is reduced. The first solution corresponds, from the tehnical point of view, to the idea of a continuous raising of the mechanization and automation level of the production processes. This fact takes place in the best conditions in continuous flow industries, where production process entropy — defined as a cybernetic industrial system — is in the main affected by the state of stability in operation of equipment and by the entropy of the object of work (probability of change in the internal structure of physic and mechanical properties, etc).

In this case, the system entropy is to be calculated as the sum of entropies of the two component sub-systems $H(\mathcal{S}) = H(\mathcal{S}_1) + H(\mathcal{S}_2)$.

On the contrary, in discontinuous flow industries the process of achieving a product implies on the one hand the addition of entropies existent in each work place and, on the other hand, the emergence of a new entropy, engendered by the relationship existing among different work places.

As a matter of fact, we will always have to do with a compound entropy

$$H(\mathcal{S}_0) = H(\mathcal{S}) + H(\mathcal{S}_0/\mathcal{S})$$

[1]) Although, this is not the object of the present study, we recall that this relationship. and even a certain quantitative relationship between these two factors, can be demonstrated,

where

$H(\mathcal{S}_0)$ = entropy of the whole discontinuous system

$H(\mathcal{S})$ = entropy of component sub-systems

$H(\mathcal{S}_0/\mathcal{S})$ = entropy of relationship between the sub-systems which are calculated (taking into account the field of conditioned probability).

The first factor is related to the intimate structure of the union of systems and may be affected to a lesser extent, almost proportional to the increase of technological entropy weight as it often happens, for instance, in continuous processes.

For these reasons the cybernetic conception on industrial processes enables us to make out — as a first conclusion — that the principal direction of acting in discontinuous flow industries is the second factor, that is the diminution of entropy engendered by the relationships between the component systems.

The transition to conveyor work and the shortening of the performance scale within the system (essentially, the reduction of the assortment) is a favourable prerequisite to this end. From a practical point of view, the conclusion resulting from the previous analysis brings about the following possibility:

Calculating the entropy specific to each cybernetic industrial process we can find some prescriptive coefficients between the elements which determine entropy, so that we may classify in a suitable way the manufacturing systems.

In our opinion, starting from the continuous systems, n classes of systems can be found, begining with those containing small enough entropy — under a certain level of entropy which could be estimated as possible in economy — and up to the maximum level to be achieved.

Among the different classes, efficiency thresholds for different types of processes and industries can be stated. In our opinion, this would considerably facilitate the management and industrial organization work, it might lead to the use and general application on national scale of the best results, introducting the typification of different elements and a general rational distribution of production processes.

2. *The relationship between entropy and the degree of organization in a manufacturing system.*

As it can be noted from the previous consideransions, the maximal efficiency in the operation of a system can be obtained when entropy is minimal

However, we must remark that this requirement of modern organization of production is always counteracted by the tendency of a continuous increase of the entropy level. The increase of entropy with a developing system may take place as a natural result of the wearing out of the technical equipment and decrease in the acting capacity of manpower, but also as a consequence of the rapid rate with which the technical scientific progress is penetrating in daily life. We shall make a short reference to this second side, which we consider to be essential. The principal ways through which the technical and scientific progress acts as a disturbing source of increase of entropy are, in our opinion, the following:

a. The increase of entropy introduced by manpower, whose qualification degree lags behind the new discoveries. Although this assertion may appear to be in contradiction with some considerations stated before with respect to the work place, such a contradiction is only apparent.

It is true that on the isolated level of a work place, the technical progress tends to lower manpower entropy by increasing technical entropy, but this occurs only during the current operation, since the transition from one operating state to another, or the elimination of some perturbations — which the technical degradation of the means of labour may introduce in the system — require the interference of manpower to a far larger extent. For instance, instead of a simple knob pressing which may suppose very limited knowledge at the moment the internal structure of an automatized mean of labour is affected, a tremendously larger amount of knowledge must interfere.

Therefore, the more we go into the cybernetic industrial systems, the more intricate becomes the management of technological processes, and a lot of new problems arise, so that on the whole the human component of entropy tends to increase.

This growth tendency of entropy is accompanied by a reaction of modern production organizer, which is the necessity of a permanent review of staff's knowledge, a permanent rise of its level, a differentiation of this level and a diversification of the scope and specialties, as well as the use of technical ancillary means during the interference of manpower in managing the industrial processes (adoption of certain decisions in agreement with data furnished by up-to-date computer system and data processing, automatical control of some processes, etc).

b. Another way through which the technical progress aiming at increasing entropy of cybernetic industrial systems is that of technological entropy. It is perfectly obvious that in as much the complexity of production means rises, in so much rises also entropy in the operation of industrial processes. Between the probability of degradation of a large amount of objects of labour achieved through the classical way and those achieved through a new technological process, it is obvious that greater risks run in the second case.

Opposite to this tendency is naturally the one directed towards achieving better and more secure technical means under stability conditions; this would result in a diminution of their technologic entropy.

Despite these precautions we take in order to avoid the tendency of growth of technological entropy, its extent is continuously growing, in our opinion. For instance, we can be sure that, in absolute value, the entropy of cybernetic industrial systems in industrialized countries is higher than the entropy of cybernetic industrial systems in developing countries. That is why we think that the problem facing the organizer of up-to-date production is to look for a reduction of its growth rate as against the general development of industrial processes.

The conclusion to be drawn in this respect: the use of a suitable method for computing the entropy of a certain cybernetic industrial system whatever brings about the possibility of introducing a new comparison criterion of efficiency in the operation of industrial organizations.

If the degree of entropy of two cybernetic industrial systems of the same type (work places, workshop, enterprises, etc.) is different, then it is obvious that their organization and evolution level is also different. The introduction of this comparison indicator offers the great advantage that it takes into account the whole lot of elements to be compared among the systems, and not among their sections, as the present methodologies recommend.

For instance, even if the means of production of an industrial organization are more expensive that those of other organizations, if they engender lower entropy in the cybernetic industrial system we may be sure that the efficiency of the respective system is higher, the same as we may be sure that not the numbers of workers originate the efficiency in operation of an industrial organization but the lowest level of human entropy they introduce into the system. Thus, if an enterprise operates with small numbers of workers as compared to another — but the entropy the workers introduce into the system originates a higher entropy of the system —, then the system is inefficient.

We have not in view to offer in this study a computation methodology of the entropy level, but to only point out that in general, with the available mathematical instruments and the technical computation and data processing means, we can find the entropy of certain cybernetic industrial systems.

Likewise, we wish to point out the conception which might underlie an analysis of the industrial activity. It may introduce a new element of economic nature, namely the turning to account of the resources which the tactor "organization" originates; this may have an essencial contribution fo the increase of the general efficiency of economic activity.

3. *Relationship between entropy and decision.*

It is known that almost all experts agree that the efficiency of a mechanism of industrial management, just as of any other economic and social system depends on the quality of decisions to be made.

Although we cannot pretend to posses accurate computation relationships hypothetically we are in favour of the existence of a close connection between the entropy level and the quality of decisions, as well as of the possibility that following detailed research, such relationship can be formed. From this very moment it is possible to modify some conceptions in the industrial management and organization, so that the value of decision may qualitatively increase.

We have in view the method of black boxes, considered as systems or aggregate of reducible or irreducible systems, related in a certain manner by direct connections or by feedback. Using this method we can apply modern mathematical theories, with an algebra proper to the block-diagrams, within which we may consider the cybernetic industrial systems as self-adjusting systems through the presence of a person or group of persons invested with the possibility of making some decisions within an interval of predeterminate values.

Applying some principles from automatics, we may consider that the workshops and sections of a factory or even the enterprises of an industrial group to be self-adjusting systems, able to measure only "inputs and out-

puts" between these systems, exclusively programming the relationship between these and leaving the totality of the other elements on the level of self-adjustment of the system.

The application of such a method might lead to a tremendous simplification of the general system of preparing and making the decisions, of the information system, etc.

The problem which arises in connection with the efficiency of this method consists, among other things, in stating the place where data required for different decisions are to be taken. We feel that the most adequate criterion for this is to find an upper limit of entropy. We have in view the technological entropy, if we consider the automatic management and control by means of an on-line computer, or the level of human entropy when the decision is adopted as such.

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L'ENTROPIE DANS LES SYSTEMES CYBERNETIQUES INDUSTRIELS

Les systèmes de l'économie peuvent être décomposés en sous-systèmes, qui se transmettent réciproquement des activités et des informations, s'influençant les uns les autres et cherchant à réaliser un processus d'autoréglage de tout le système, tout en gardant la caractéristique fondamentale des systèmes cybernétiques. Au point de vue de la cybernétique, la présence de certaines structures de grande complexité, mais finies, signifie aussi l'existence d'une indétermination assez importante. C'est de là que provient la première hypothèse sur qui repose l'étude, c'est à dire que les systèmes cybernétiques industriels sont des systemes qui tendent à transformer la petite entropie en une entropie haute, ce qui signifie entropie grandissante.

Le système cybernétique irréductible dans l'industrie c'est le lieu de travail, caractérisé par le sous-système force de travail (homme), le sous-système moyens de travail (machine) et le sous-système objet du travail (matières premières, matériaux, pièces à traiter). Le sous-système homme est un système cybernétique indépendent et les deux autres sont des systèmes quelconques temporels. Ces deux systèmes peuvent être considérés comme des sous-systèmes d'entropie finie, positive ou nule.

On remarque que l'entropie du système cybernétique irréductible apparait, surtout, comme un résultat de la variation de la probabilité d'action de l'élément humain.

Si, sur le lieu de travail on passe à la mécanisation ou à l'automation des moyens de production, l'entropie du système cybernétique irréductible se modifie, en réussissant en général à être determinée par le niveau technique.

Un système cybernétique industriel qui est formé par des ensembles de systèmes cybernétiques irréductibles est d'autant mieux organisé que le niveau de l'entropie, établi à l'échelle du système entier, est plus réduit.

Dans les industries à flux discontinu, l'entropie du système est égale à la somme des entropies des sous-systèmes composants.

La diminution de l'entropie du système cybernétique industriel peut se réaliser par deux voies: l'établissement d'une répartition convenable des sous-systèmes, de sorte que leur structure entière contienne une entropie minime; la réduction de l'entropie sur chaque lieu de travail.

L'existence d'un certain niveau d'entropie fait que les processus industriels aient toujours une évolution probabilistique, sa prévision contenant un certain facteur d'erreur. La grandeur de cette erreur est inversement proportionnelle au niveau de l'entropie.

Dans les industries à flux discontinu, la principale voie d'agissement en vue de la réduction du niveau de l'entropie est l'amoindrissement de l'entropie, générée par les relations entre les systèmes composants. A cet effet, on peut établir *n* classes de systémes, à commencer par celles de petite entropie et jusqu'au niveau maximum. Entre les différentes classes on pourrait établir des degrès d'efficacité pour les différents types de processus et d'industries, thème que l'auteur se propose de traiter dans les études futures.

ЭНТРОПИЯ В ПРОМЫШЛЕННЫХ КИБЕРНЕТИЧЕСКИХ СИСТЕМАХ

Сохраняя основную характеристику кибернетических систем, системы в народном хозяйстве могут быть разделены на подсистемы, которые взаимно передают виды деятельности и информацию, оказывают влияние друг на друга и стремятся осуществлять процесс саморегулирования всей системы. С точки зрения кибернетики наличие высококомплексных, но конечных структур означает и наличие большой степени неопределенности. Отсюда вытекает первое предположение, заложенное в основу настоящей статьи, а именно — промышленные кибернетические системы являются системами, которые стремятся к превращению низкой энтропии в высокую, то-есть в возрастающую энтропию.

Несводимой кибернетической системой в промышленности является рабочее место, характеризующееся подсистемой «рабочая сила» (человек), подсистемой «рабочие средства» (машина) и подсистемой «предмет труда» (сырье, материалы, обрабатываемые детали). Подсистема «человек» является независимой кибернетической системой, а остальные две подсистемы представляют собой некоторые временные системы. Эти две подсистемы можно считать подсистемами конечной энтропии, положительной или нулевой.

Обращает на себя внимание то обстоятельство, что энтропия несводимой кибернетической системы является, в основном, результатом изменения вероятности действия людского элемента.

В случае, если на рабочем месте переходят к механизации или автоматизации рабочих средств, энтропия несводимой кибернетической системы изменяется техническим уровнем.

Промышленная кибернетическая система, состоящая из объединений несводимых кибернетических систем, тем лучше организована, чем ниже уровень энтропии, устанавливаемый в масштабе всей системы.

В видах промышленности с прерывистым потоком энтропия системы равна сумме энтропий составляющих подсистем.

Снижение энтропии промышленной кибернетической системы может осуществляться двумя путями:

— установлением подходящих разделений подсистем таким образом, чтобы вся их структура имела наименьшую энтропию;

— снижением энтропии на каждом рабочем месте.

Наличие определенного уровния энтропии обусловливает то обстоятельство, что промышленные процессы всегда имеют вероятностное развитие, прогноз которого содержит определенный фактор погрешности. Величина этой погрешности обратно пропорциональна уровню энтропии.

В видах промышленности с прерывистым потоком основным направлением воздействия с целью снижения уровня энтропии является уменьшение энтропии, порождаемой отношениями между составляющими системами. С этой целью можно установить *n* классов систем, начиная от систем с низкой энтропией и вплоть до максимально осуществимого уровня. Между различными классами можно было бы установить пределы эффективности для различных типов процессов и видов промышленности; автор предлагает эту проблему к дальнейшему изучению.