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07616

United Nations
Centre for Industrial Development

Original: English

Inter-Regional Symposium on Industrial
Project Evaluation

CID/IPE/B.21
Discussion Paper

Prague, Czechoslovakia
11 - 29 October, 1965

STUDY OF INDUSTRIAL PLANT SYSTEMS

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65-41405

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1. FOREWORD

1.1 Scope of Report

1.1.1. The economic feasibility of an industrial plant can be rationally ascertained once market studies have been carried out to evaluate the amount of expected sales, alongside with studies on the procurement sources of the raw materials required.

It should be borne in mind that both the sales market and the procurement sources are the same for the various industries which operate in a certain region and, in this sense, these industries can therefore be considered interconnected.

All the industries in the same region contribute in its economic development and each of them should fit into the overall economic framework without causing any unbalance in production.

The industrial plants operating in a certain region may be considered as forming a complex system the optimization of which should be aimed at in the dynamic process of industrial development.

In evaluating the economic feasibility of an industrial venture, the likely perturbation of the existing situation should be taken into account, and an estimate of the probable positive and negative consequences should be made.

In order to do so, one must have the technical instruments allowing the control of the entire present and prospective industrial activity in the region concerned.

1.1.2. ELC have dealt with several problems of this nature for the solution of which they have formulated and tried out appropriate media. This report gives a description of some of the procedures perfected, mainly outlining the objectives of each study and the guiding principles followed.

The examples referring to hydroelectric plants all regard cases which were put into practice with satisfactory results.

1.2 Objective of Studies Performed

1.2.1. The studies carried out in an organic form from 1960 were designed for the following two purposes:

a. Optimization of the solution of the problems considered

b. Optimization of the organizational work system with a view to achieving the best possible results within the shortest time and at the lowest cost.

Efforts were concentrated, in brief, at selecting and working out the most appropriate methodology to tackle and successfully solve the most complex problems under investigation, with particular reference to the hydroelectric power industry.

The "best possible solution" is considered to be that which is the most satisfactory, at the time of its implementation in the light of the economic and political situation in the region concerned.

The technical optimization is intended to supply those called upon to make decisions with as clear and complete a picture as possible of the technically practicable solutions for the specific problems concerned.

In consideration of the complexity of the problems involved, the most appropriate and powerful media were resorted to right from the start; ELC for this purpose employed the experience and cooperation of the calculation centers of IBM Italia and of Olivetti, Divisione Elettronica.

In the course of the studies, some of the initial ideas were readjusted, new concepts were introduced and a certain number of procedures developed to a higher degree as appeared more suitable in the light of practical results.

For obvious organizational reasons, these studies had to be confined within reasonable time and cost limits and had to yield concrete results in the short run, without interfering with the normal design work.

The discipline eventually proved to have a beneficial influence on the engineering work as it compelled the engineers involved to focus their attention on only the essential lines, thus helping to refine their capacity of analysis and synthesis.

1.3 Guiding Principles

A certain number of guiding principles were established right from the start and constantly followed, thus helping to make the team work unitary and organic.

These guiding principles can be summarized as follows:

a. Delimitation of the objectives to be achieved and of the field of action of the various engineers involved

b. Freely critical analysis of the conventional procedures

c. Definition of common general principles for all the problems investigated.

At the outset of each study, great care was taken that the scope of the study and the objectives to be attained be clearly defined, thus giving rise to a communion of ideas and intent among the various members of the team.

In the choice of calculation procedures, the conventional methods of analysis have been adopted only in those cases where their conceptual validity had been thoroughly ascertained. Attempts were then made to generalize the procedures for the singling out of the elements of general interest, thus making it possible to extrapolate the results obtained to different fields of application.

The fixing of the liberty of investigation initially gave rise to some difficulties but the advantages obtained have been noteworthy, under the following main aspects:

- concepts and procedures which proved obsolete and inadequate were set aside
- new procedures with a high degree of efficiency were developed

- the engineers were assisted in the use of constructive criticism and creative faculties [1]

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1) On this item see considerations of R.K. Linsley in "Economics and Public Policy in Water Resources Development", Chapter 7, Engineering and Economics in Project Planning, IOWA State University Press, 1964

2.1 Concept

An industrial plant is basically a technical means of producing goods or facilities required by the community. Its implementation must be justified by the existence of a market capable of absorbing the expected production and by the possibility of economical procurement of the raw materials to be processed.

The plant must be designed and conceived so as to turn out its products with the highest possible degree of efficiency. A series of industrial plants serving the same market form a complete system which can be considered interconnected, as each plant mutually conditions and integrates with the others.

Industries producing the same goods can be regarded as directly interconnected, whereas industries serving the same market but producing different goods may be considered indirectly interconnected.

The concepts outlined above naturally apply to both developing and developed countries, regardless of their political systems.

2.2 Mathematical Model

The planning of an industrial plant, including the relevant market studies and the investigation of procurement sources, is in general rather complex, due to the large number of parameters involved, each with its own variability interval.

It is therefore necessary to develop appropriate media for the analysis, as well as for checking and representation of the project. To achieve this purpose, the project should be broken up into schematic lines through a process of analysis consisting in the tracing of its basic elements and then, through a process of synthesis, the reconstruction of the logic of project unit should be achieved.

In this way the mathematical model of the project is obtained after having clarified the terms and dimensions of the project;it then forms the technical basis for further elaborations.

If the mathematical models of different plants are connected with each other in time and space, we obtain the mathematical model of an industrial plant system.

The numerous instances in which this procedure has been applied confirmed its validity, regardless of the complexity of the problems dealt with,and of the type of subsequent elaborations, or the technical means employed.

2.3 Simulation

Once the mathematical model of the plant or system of plants has been obtained, one can apply to it the technique of simulation which consists basically in artificially reproducing the production process, according to probable hypotheses.

For instance, once the features of the different plants have been fixed, one can simulate the finished goods, with the determination of the relevant quantities and times of production.

Or, the other way round, on the basis of a given demand of finished goods, one can simulate the production, tracing back the quantities and times of delivery of the required raw materials, thus making it possible to check their availability and organize their transportation.

In practice, checking procedures are adopted which can easily be extended to a large variety of hypotheses and also allow the solution of design problems.

Stochastic processes can also be reproduced in the simulation and this possibility will help considerably in gaining a better knowledge of certain components of industrial development which have not so far been thoroughly investigated.

3 PRACTICAL EXAMPLES

3.1 Hydroelectric Plant

3.1.1. A hydroelectric plant is an industrial plant utilizing the runoff of a catchment basin for the generation of energy.

Runoff can be considered of a stochastic 2) nature, whereas the demand of energy is of a prevalently deterministic character.

A hydroelectric plant consists basically of a reservoir, a diversion tunnel, a surge tank, penstocks and a power house, as shown in fig. 1.

Conceptually, we have a storage capacity which is fed by the natural or regulated flow from other reservoirs and serves its purpose by supplying energy according to demand.

The queuing theory 3) in which each separate demand is considered in turn, applies to this problem and interesting applications of it have already been achieved.

For the sake of simplicity, though this is conceptually less correct, we can also consider that the measured flows are fed into the reservoir in their chronological sequence.

Provided that fairly long observation periods are on record, this method may nevertheless yield sufficiently indicative results.

The models prepared by ELC were laid out so as to make it possible to utilize either procedure.

2) In these items see: Ven-te-Chow - Handbook of Applied Hydrology - Section 8-1 and attached references

3) P.A.P Moran : A probability theory of Dams and Reservoir Design - Australian Jour. of Applied Sci., v.5., Pp 116-124, 1954
I.B. Langbein : Queuing Theory and Water Storage Proceedings of ASCE, paper 1811 Hy. 5, october 1958
Design of Water Resource Systems, Part III, Chapter 14, Haward University Press, 1962
For more complete references see : Ven-le-Chow, Handbook of Applied Hydrology

SCHEME OF A HYDROELECTRIC PLANT

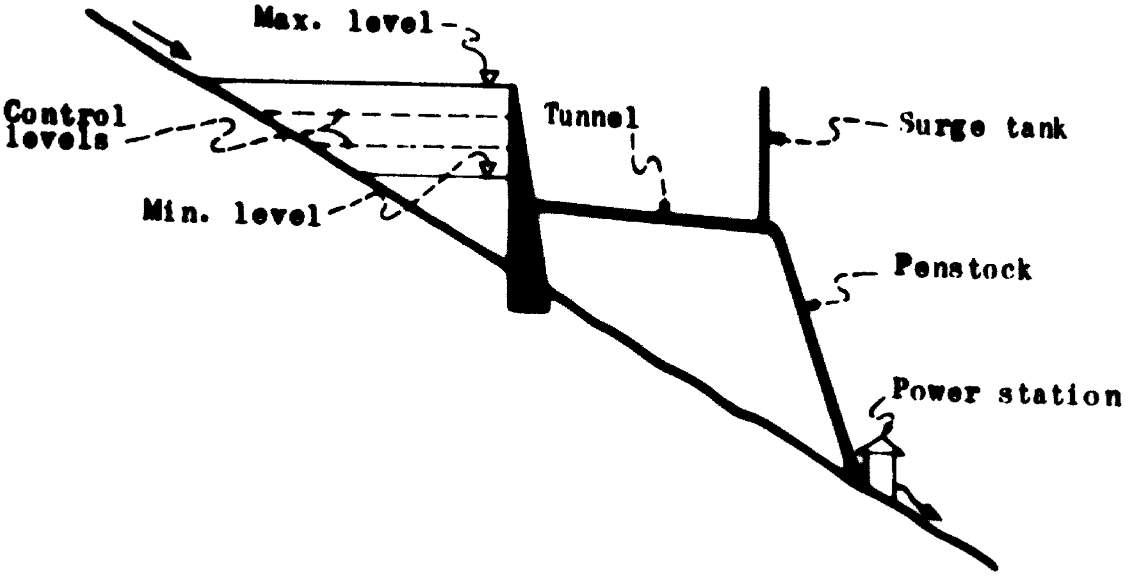

Fig. 1

3.1.2. The mathematical model of a hydroelectric plant is, conceptually, rather simple. (fig. 1)

The reservoir may be filled to maximum water level, to minimum water level or to an intermediate level. The flow requirements may be higher, equal to or lower than the natural flow in the same time interval.

If the reservoir is filled to maximum water level, in the first instance a certain amount of water will be spilt, in the second instance the waterline will remain at maximum level, in the third instance the level will subside.

If the reservoir is drawn down to minimum water level, in the first instance water level will rise, with or without spilling over, in the second instance it will remain at minimum level and will meet demand, in the third instance it will remain at minimum level but will be unable to fully meet demand.

In intermediate cases, water level will rise (either spilling over or not), or will subside (either meeting demand or not).

These basic concepts are worked out and applied indifferently to water or energy demands, taking into account such elements as evaporation losses, particular operation standards, etc., thus achieving very complex and highly perfected models.

3.2 Hydroelectric Systems

3.2.1. A certain number of hydroelectric plants feeding the same network form a hydroelectric system 4)

An example is attached hereto of calculations made with an IBM 704 computer on a system of three interconnected hydroelectric plants referred to as A,B and C.

The load diagram of the network and persistency (i.e. the time in percent during which energy demand must be fully met) were given. In the case under consideration, persistency was taken to be 95%

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4) On this item see: [illegible].J. Lewis and L.A. Schoemaker-Hydrosystem Power Analisis by digital computer - Proceeding of ASCE, May 1962
V. Gramignani, L. Bernard - Estudio de un Sistema de Plantas Hydroelectricas con elaborador electronico der Congreso Peruano de Ingenieria Eléctrica - Lima 1963

For references see: Handbook of Applied Hydrology and Design of Water Resource Systems (previously indicated)

Plants A and B belong to the same watershed and are placed in series, while plant C is located in a different watershed.

In this case, affluent flows were considered in their chronological sequence and the relevant averages have been worked out every ten days.

3.2.2. Prior to starting calculations, the technical features of the plants, as summarized in Table I, must be defined, as well as the specific function assigned to each plant in the interconnected system. In the case under consideration, plant A supplies energy according to its own technical features and of the runoff from its direct watershed, plant B supplies energy to make up for the deficiencies of plant A, while the purpose of plant C is to make up for the deficiencies of A+B.

On the whole, the three plants meet demand with a persistency of 95%, which was traced back through a series of successive approximations.

The productive capacity of the plants having thus been obtained (table 2), the problem is to choose the most appropriate distribution of the capacity to be installed. If, for instance, the load diagram shows a peak equal to twice the average capacity, in the case of a single plant, the capacity installed should be twice the average. In the case of two separate plants, if these have different operation periods, a capacity four times the average should be provided.

As the operation of the plants in a system is complementary, all probable combination should be examined with a view to optimizing the choice of the capacities to be installed in each of the plants.

This research which is generally rather complicated is carried out automatically through an original procedure developed for the specific purpose.

Once the installed capacity has been defined, the dimensions of the diversion works and power house can be fixed, on the basis mainly of technically permissible velocities and diameters.

The results of the dimensioning study are set forth in table 3.

Once the dimensions of the different works have been fixed, it is possible to estimate their cost on the basis of the unit cost tables expressly prepared and fed stored in the computer's memory. The results obtained are shown in table 4.

```
IMPIANTI                                     A                   B                C
LIVELLO MASSIMO INVASO   MSM           245.00              146.00           598.00
LIVELLO MINIMO INVASO    MSM           229.60              146.00           584.00
LIVELLO INIZIALE         MSM           245.00              146.00           598.00
VOLUME INIZIALE        MCUBI     0.210000E 09    0.                   0.156000E 10
CAPACITA UTILE         MCUBI     0.112000E 09    0.                   0.138000E 10
PRIMO LIVELLO GUARDIA    MSM           241.27              146.00           594.57
SECONDO LIVELLO GUARDIA  MSM           235.89              146.00           590.30
POTENZA MEDIA MASSIMA     KW           40000.              80000.           80000.
```

PLANTS
MAXIMUM WATER LEVEL
MINIMUM WATER LEVEL
INITIAL LEVEL
INITIAL VOLUME
NET STORAGE
FIRST CONTROL LEVEL
SECOND CONTROL LEVEL
AVERAGE MAXIMUM POWER

TABLE 1

```
IMPIANTO  A

  ANNO TEMPO     Q      QA      QD      QS      QE     LIV    SALTO   PERD     PCT     DEF    VOL
  1943   1     7.51   75.10   75.10    0.      0.   146.00   58.62   0.38   36097.  12028. 0.
  1943   2     6.12   74.90   74.90    0.      0.   146.00   58.62   0.33   36001.  15910. 0.
  1943   3     7.10   12.17   12.17    0.      0.   146.00   58.99   0.01    5697.  79678. 0.
  1943   4     9.13   18.10   18.10    0.      0.   146.00   58.98   0.02    8753.  74843. 0.
  1943   5    19.49   57.90   57.90    0.      0.   146.00   58.77   0.23   27904.  41029. 0.
  1943   6    10.62   25.20   25.20    0.      0.   146.00   58.96   0.04   12183.  68589. 0
  1943   7    10.56   14.00   14.00    0.      0.   146.00   58.99   0.0
  1943   8     9.15   30.90   30.90    0.      0
  1943   9     6.01   12.60
  1943  10
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
                                                                                    0. 0.
                                                              0.69   48125.       0. 0.
                                               0.   146.00   56.31   0.69   48125.       0. 0.
                                98.59    0.      0.   146.00   58.34   0.66   47162.    963. 0.
         33   16.00   85.51   85.51    0.      0.   146.00   58.50   0.50   41020.   7105. 0.
  1954  34   12.66   86.76   86.76    0.      0.   146.00   58.49   0.51   41611.   6514. 0.
  1954  35   34.57  109.62  105.46    4.17    0.   146.00   58.25   0.75   50371.       0. 0.
  1954  36   13.70   31.38   31.38    0.      0.   146.00   58.93   0.07   15164.  64090. 0.

  ANNO            QM     QAM     QDM     QSM    QEM    LIVM   SALTOM  PERDM    POTM    DEFM        VOLM
  1954        124.68  367.68   97.25  270.43     0.  146.00   58.35   0.65   46520.   2531. 0.

  PERIODO         QM     QAM     QDM     QSM    QEM    LIVM   SALTOM  PERDM    POTM    DEFM        VOLM
               56.34  164.83   75.38   89.44     0.  146.00   58.53   0.47   36105.  22143. 0.

   PRODUCIBILITA MEDIA      PRODUCIBILITA MEDIA CORRETTA      POTENZA MEDIA CORRETTA      DIFF VOL
     316.276 GWH                    316.276 GWH                      36105. Kw                0.
```

ANNO	year of observation
TEMPO	index of week, or month
Q	flow of the natural catchment area
Q_A	flow entering the reservoir
Q_D	flow exploited for energy production
Q_S	spillway flow
Q_E	evaporated flow
LIV	level of the reservoir
SALTO	head
PERD	hydraulic head loss
POT	power obtained
DEF	power to be provided by other plants of the considered system in order to reach the total power with persistence p
VOL	volume of the reservoir

The symbols with index M indicate the average values.

TABLE 2

PLANT B

INSTALLED POWER
CAPACITY FACTOR
NUMBER OF TUNNELS
LENGTH OF TUNNELS
DIAMETER OF TUNNELS
NUMBER OF PENSTOCKS
LENGTH OF PENSTOCKS
DIAMETER OF PENSTOCKS
NUMBER OF OUTLETS
LENGTH OF OUTLETS
DIAMETER OF OUTLETS

```
IMPIANTO   B

POTENZA INSTALLATA     KW       55776.
CAPACITY FACTOR                 0.6473
NUMERO GALLERIE                     1.
LUNGHEZZA GALLERIE     M       1300.00
DIAMETRO GALLERIE      M          6.5C
NUMERO CONDOTTE FORZATE             2.
LUNGHEZZA CONDOTTE FORZM        100.30
DIAMETRO CONDOTTE FORZ M          3.85
NUMERO SCARICHI                     1.
LUNGHEZZA SCARICHI     M          C.
DIAMETRO SCARICO  .    M          7.82
```

TABLE 3

FIXED COSTS	COSTI FISSI	$	2400000.
COST OF DAM	COSTO DIGA	$	6858000.
COST OF INTAKES	COSTO PRESE	$	6273.
COST OF TUNNELS	COSTO GALLERIE	$	1755758.
COST OF SURGE TANK	COSTO POZZO PIEZOMETR	$	487606.
COST OF PENSTOCKS	COSTO CONDOTTE	$	172605.
COST OF MACHINERY	COSTO MACCHINARIO	$	3682839.
COST OF POWER STATION CIVIL WORKS	COSTO OP CIV CENTRALE	$	700362.
COST OF OUTLETS	COSTO SCARICHI	$	0.
TOTAL COST	COSTO TOTALE	$	16063442.
GENERATION CAPACITY	PRODUCIBILITA	GWH	316.276
COST OF kWh	COSTO KWH	$/KWH	0.050789

TABLE 4

PLANT IMPIANTO	PRODUCTION $(KWh \cdot 10^6)$ PRODUCIBILITA GWH	COSTS COSTI $	CAPITAL COST COSTO CAPITALE $/KWH
A	260.260	26394054.	0.101414
B	316.276	16063442.	0.050789
C	193.257	21413729.	0.110804
	-----------	-----------	
TOTALI TOTALS	769.793	63871225.	0.082972

TABLE 5

Subsequently, for the sake of convenience, the principal summarized results are obtained, as given in table 5.

The logic process described above is schematized in the flow chart which appears in fig. 2.

3.3 Optimization

Every technical or economic hypothesis has its corresponding optimal solution which is indicated by the computer.

Grouping the various hypotesis and making them vary within appropriate limits a sufficiently large series of solutions is obtained to make it possible to define the range of solutions in which the optimal solution is sure to be found.

The relevant basic results can be set forth in the form of a diagram so as to make them self-evident.

An example of such a representation is given by fig. 3 drawn from a study, completed in 1962, on the interconnection of hydroelectric plants.

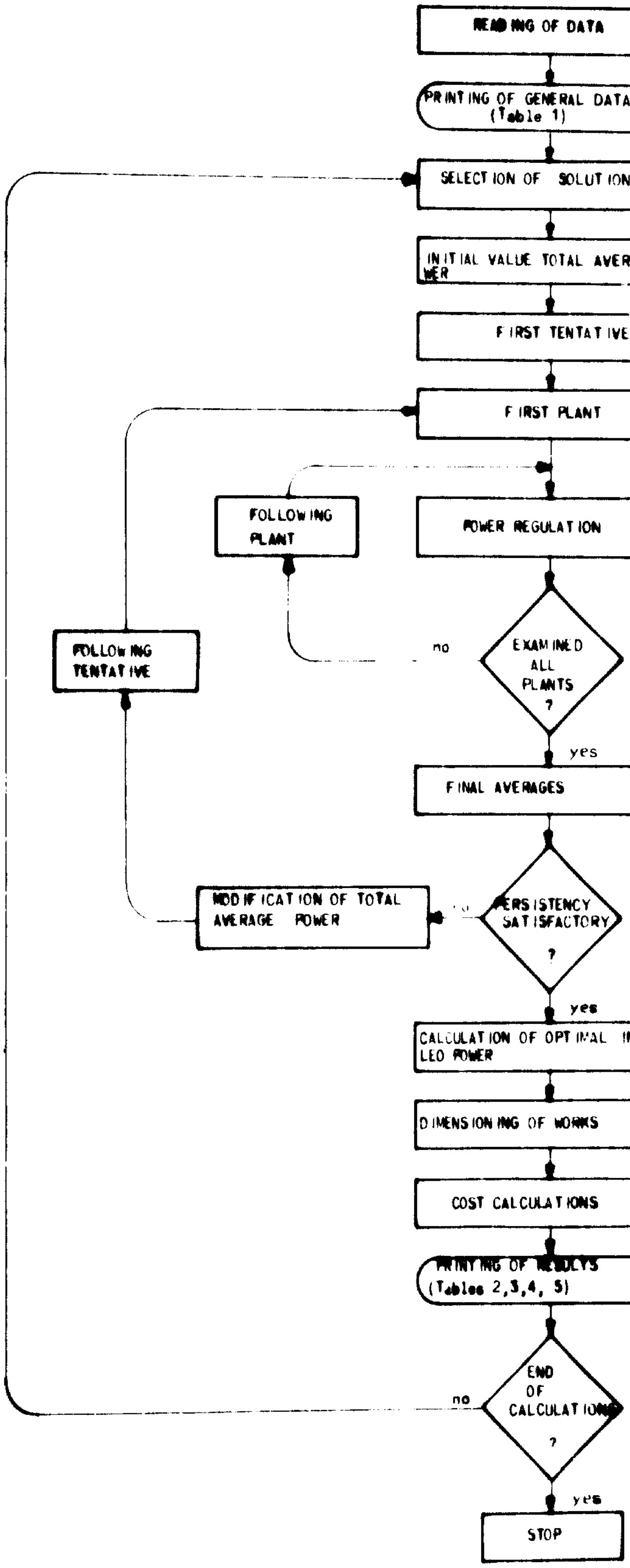
Every single point along the continous lines represents an optimized system, well defined in all its technical and economic aspects.

For instance, if a generation of 1500.10^6 kWh/year is to be obtained, it is advisable to adopt the D+E+A system which calls for a lower unit capital investment than the D+E+(A+B) system or other alternatives.

If however requirements are expected to exceed the abovementioned figure, D+E+(A+B) system should be selected as this allows generation up to 2300.10^6 kWh/year.

In the light of a representation of this type, those called upon to make decisions can easily make their choice, taking into account also such additional economic and social factors as may not be known to the engineers.

GENERAL FLOW CHART Figure 2



CAPITAL INVESTMENTS AND OPERATING COSTS

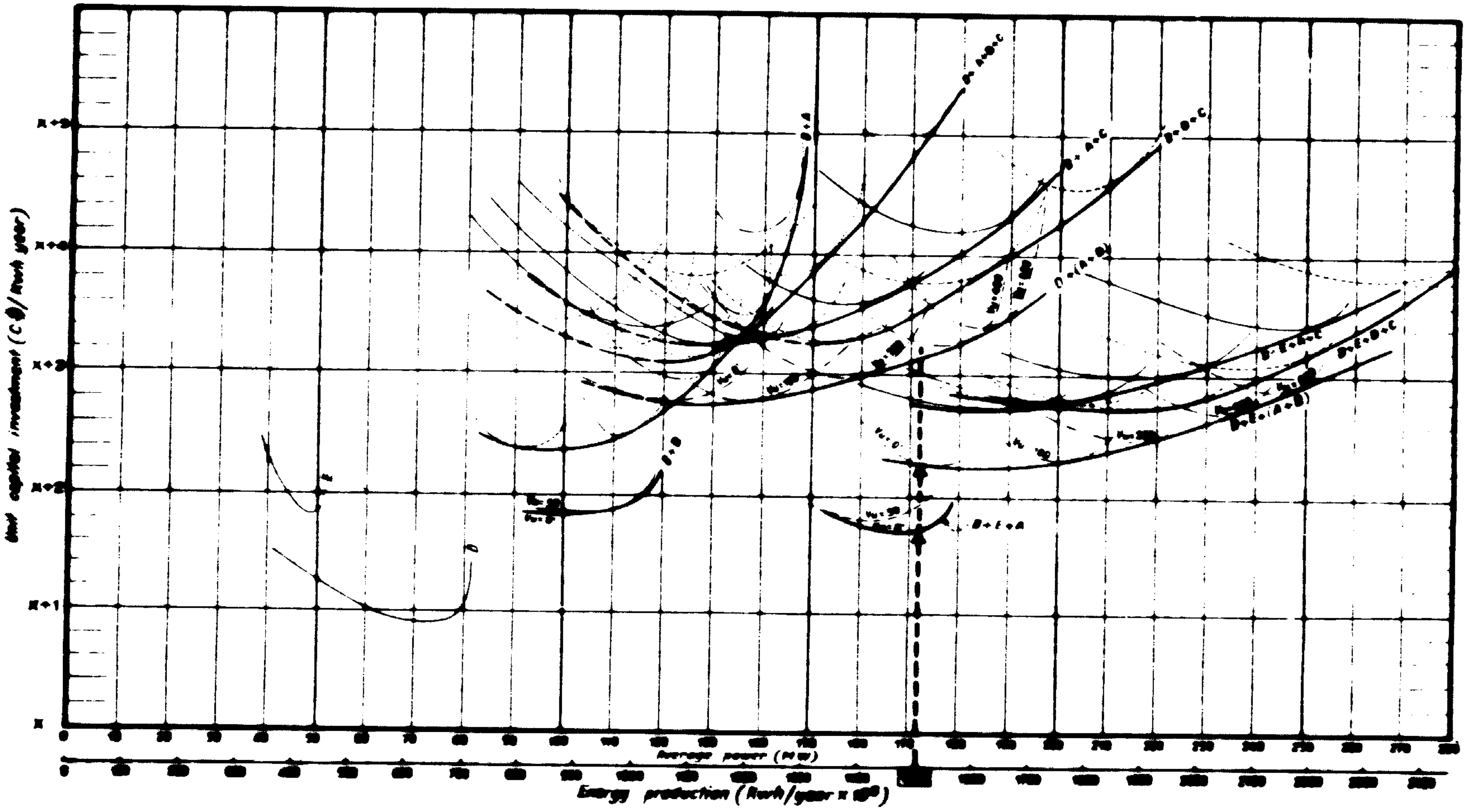


Fig. 3

1 GENERALIZATION

1.1 Invariants

Any industrial plant can be treated with the same methodology as described in the case of the hydroelectric system.

The position of the problem therefore remains the same in relation to any plant whatsoever, of an industrial nature. This also applies to any problem the purpose of which is the optimization of any service for the processing of products.

In the specific case of the hydroelectric plant, the river, the reservoir, and the other basic components shown in fig. 1 are also invariants, as they are to be found in all hydroelectric plants.

Within the framework of the plant layout, some of the invariants can be equalled to zero without destroying the logic of operation.

Be, for instance the reservoir = 0, we will have a run of the river plant; if the power station = 0 the plant will generate no energy but it will supply water, say, for irrigation purposes.

Once the invariants in a problem of flow utilization have been singled out, the same mathematical model can be applied to power generation problems or to problems of water supply for irrigation or for multipurpose solutions.

Once the invariants in common between a problem of flow utilization and one of industrial production have been singled out, one can utilize the same mathematical model structure in dealing with a hydroelectric plant and with an industrial plant destined for any other purpose.

The raw materials for an industry can be compared to the flow to be utilized; the finished product of an industry can be compared to the power produced by an hydroelectric plant.

The logic in the producing process is therefore analogous, and such is the structure of the mathematical model.

Taking into account a system of plants the analogy persists, since the logic of the interconnection is identical.

The singling out of the invariants is fundamental for the correct formulation of the various problems and is of considerable practical interest as it affords the possibility of applying the experience gained in the study of one problem to another problem apparently quite different.

1.2 Parameters

For the solution of any problem, one resorts to a series of logical and numeric relationships which form the algorith of the problem. The problem is represented by the algorithm by means of parameters that can be defined as the minor and indivisible functional elements.

In the case of the hydroelectric system described above, the parameters are, for instance, the different compoments of the plant such as tunnel and penstock, together with the related technical and economic elements which would appear meaningless if considered separately.

The parameters do not have an absolute value like the invariants, as they are linked with a specific problem and its dimensions and may vary according to the degree of accuracy required.

The fixing of parameters is of paramount importance in the preparation of mathematical models which practically consists of single parameters logically interconnected.

1.3 Examples

The studies, based on constant attempts towards generalization, through the research of invariants and parameters gave excellent and sometimes unpredictable results.

In the field of water resources utilization, it was possible to achieve extremely flexible mathematical models by means of which similar problems can be represented, tackled and solved.

The possibility of switching from one field of application to an apparently different one has been repeatedly confirmed.

In ELC 5), for instance, use was made of a programme prepared by Olivetti-Divisione Elettronica for the calculation of 3-dimensional frameworks 6) for the solution of rock mechanics problems.

The staff who prepared the programme certainly did not have rock mechanics in mind but the study was well laid out in general terms and was found to afford effective media which could be applied to fields falling outside the original scope.

Also the queuing theory proved to have a very vast range of applicability, as it allows investigation of all those phenomena which can be represented by a network consisting of nodes and oriented arcs.

By this theory, it was possible to utilize practically the same programmes for both job organization and urban traffic problems with highly rewarding practical results 7)

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5) A note of P.J. Fulberth has been presented in 15th Colloquium on Safety in Rock Engineering, Salzburg September 1964

6) A. Pizzarello - Risoluzione di Problemi di statica delle costruzioni mediante un elaboratore elettronico - Olivetti S.p.A.

7) V. Gramignani - L. Mazzon - Traffic in Towns with Historical Monumental Area First Meeting "Road Traffic Technique" - ACI - BP - Palermo - Maggio 1964

CONCLUSIONS

Industrial plants are systems which should be studied with appropriate methodology and technical media.

The technique of simulation, with mathematical models, affords considerable advantages, as it allows the obtaining of satisfactory results in problems which could not be resolved in a practical manner by the conventional methods of analysis.

Every single problem should be laid out in terms as general as possible, as this allows the utilization of the same media in apparently different fields of application.

A process of the merging of technical branches that were originally considered different is now taking place. Such a process is made possible by the present availability of certain very powerful calculation instruments.

The methodologic problem should be studied with particular attention as it can afford the partial solution of complex problems.

This should be taken into consideration by the U.N. experts when preparing the envisaged Manual on Industrial Project Evaluation.

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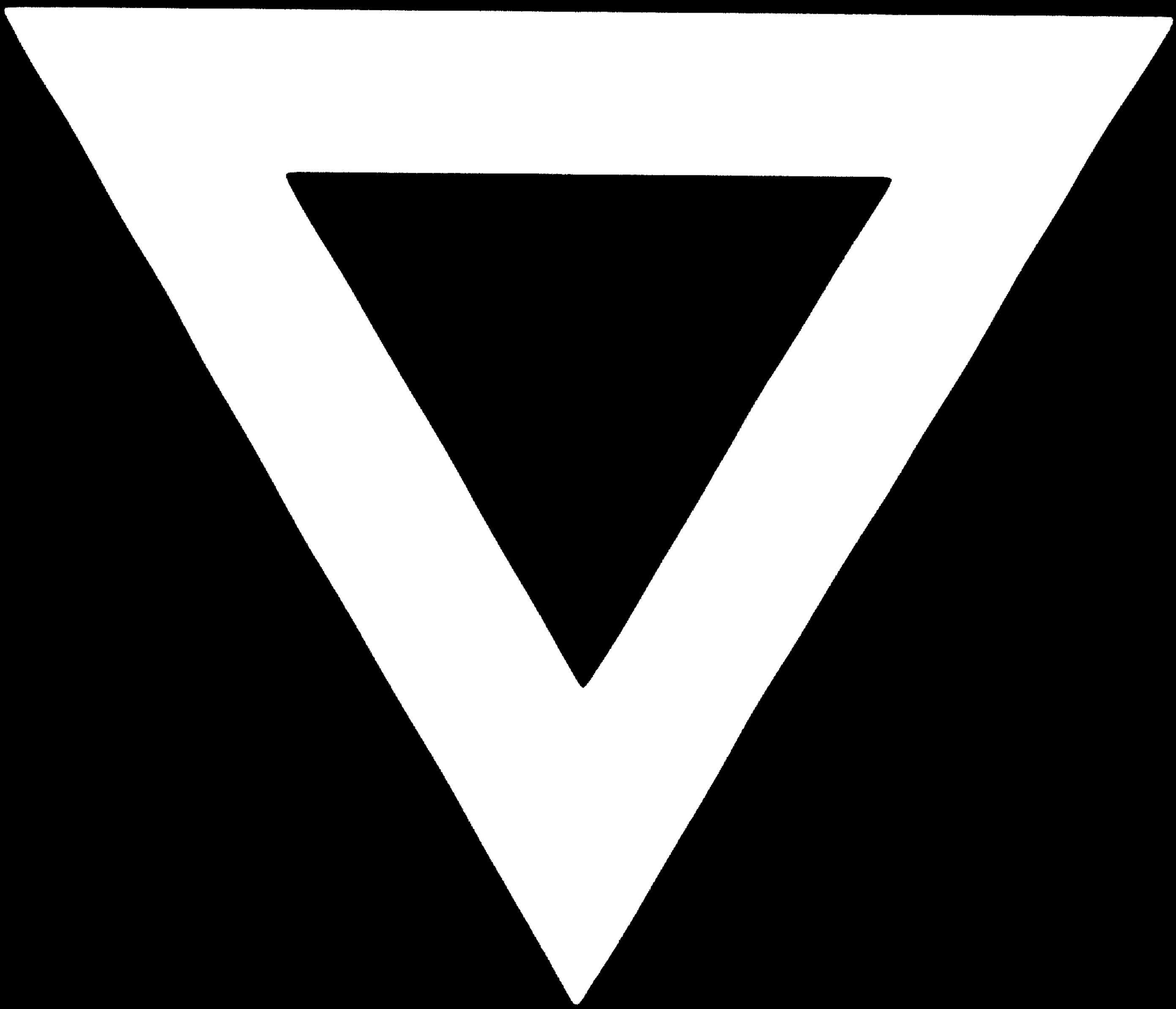

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