A SYSTEM DYNAMICS BASED STRATEGIC PLANNING MODEL FOR HYDROELECTRIC SYSTEMS

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ABSTRACT

This work presents a new methodology for supporting the strategic planning process in a corporation dedicated to hydroelectric generation. Concepts of strategic planning are presented initially, followed by the provision of supportive material for the development of a computer model representing the operational scheme, and concluding with examples of its application.

This type of company may be the result of either the incentive to competitive generation within the power sector, or the result of the unbundling of previously integrated utilities [1], [2].

The model comprises two sub-models: the technical performance sub-model and the managerial sub-model. The paper emphasises the aspects related to the managerial model.

KEYWORDS

Operation Systems, System Dynamics, Strategic Planning, Stochastic Simulation

1. INTRODUCTION

Strategic planning is a process that seeks to translate managerial objectives into policies and allocations of resources that will permit attaining these objectives. This process generally passes through the following stages: establishment of corporate objectives and targets; evaluation of the trends in the economic, political, technological and competitive environments; identification of potential opportunities and threats; and the development of strategies, policies and allocation of resources to face the threats and to take advantage of the opportunities.

Many firms fail to attain their corporate objectives due to the use of planning tools that are unsuitable for the ever-changing business environment. This problem may be dealt with by means of simulation models that permit to anticipate potential problems and to design and evaluate operational policies and strategies to minimise their effects.

In the case of a hydro generating utility, the simulation model must take into account both the technical aspects and the management process of the corporation. The technical sub-model aims to determine the generating capacity and a performance index that takes into account the inflows to the reservoirs, maintenance schemes and forced shutdowns of the generator units. The management sub-model gets the results of the technical model to determine the technical-economical consequences of the corporate policies. A feedback loop exists between the sub-models due to the necessity for a new technical evaluation of some management decisions.

2. MANAGERIAL MODEL

A typical hydro generation utility is composed of two main management sectors: technical management and financial management. Each management sector, in turn, is divided into areas of activity. For example, the technical management may be divided into areas of project, operation and maintenance; the financial management into areas of resources and materials.

Each area of activity is a hierarchical structure with specific objectives and aims. Sometimes, there are discrepancies of objectives and aims in the same management sector. These conflicts may result in loss of generating capacity. The objectives and aims of each area is described next, presenting the functions of the technical areas in accordance with their causal connections.

2.1 <u>**Areas of the technical management**</u>

2.1.1 - **Project area**

In an enterprise generating electricity that is already in its operational phase, the projects have two principal origins: the need for technological updating of the installations and exceptional services, such as, for example, the increase in the installed capacity. The project area has the objetive of concluding the requested services, within the pre-established time limits. To this end it possesses a staff of employees and the possibility of contracting outside services. Figure 1 summarizes the principal functions of this area.

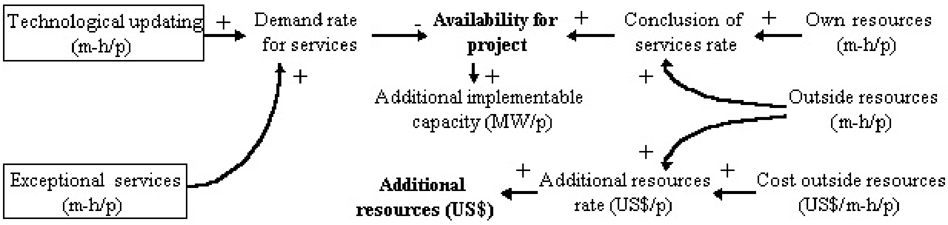

Fig. 1 - Causal Diagram of the Project Area

The *Availability for the project,* in Man-hours (m-h) depend on the *Demand rate for services*, in Man-hours per period (m-h/p) and on the *Conclusion of services rate* (m-h/p). Since the demand for service occurs in an "almost" continuous manner and the *Conclusion of services rate* depends on the availability of resources, within the area there exists an established dynamic process affected as much by internal factors (Resourses) as by external ones (Demand for services).

2.1.2 - **Operation Area**

Is the area in charge of the production and operation of the generating plant. The principal aim of this area is the fulfillment of the contractual objectives of supply, for example, in MW per period (MW/p). Its principal functions and the interactions with the other areas are represented in Figure 2, which also presents the interface with the technical sub-model.

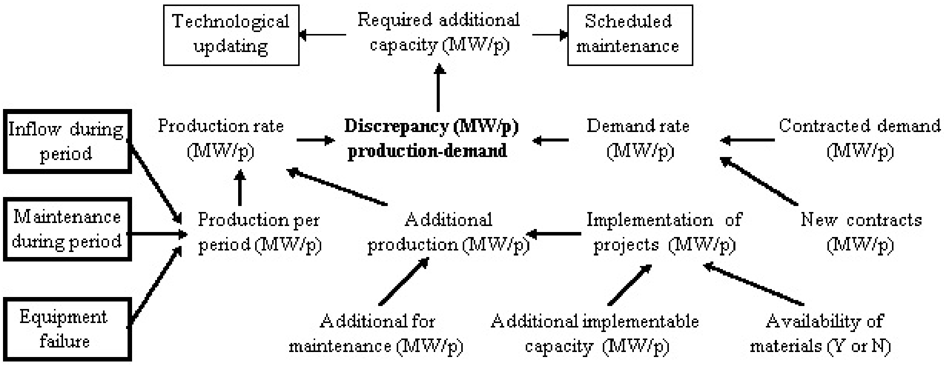

Fig. 2 - Causal Diagram of the Operation Area

2.1.3 - **Maintenance Area**

The principal aim of this area is to implement maintenance schedules. To this end, it possesses a staff of employees and the possibility of contracting outside services. Fig. 3 summarizes the main functions of this area.

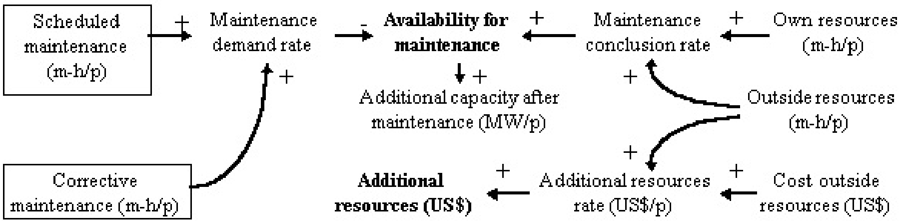

Fig. 3 - Causal Diagram of the Maintenance Area

2.2 <u>**Financial Management Areas**</u>

2.2.1 - **Resources Area**

Is responsible for the management of the income and the expenditures of the corporation. Income can originate as much from the sale of energy as from external resources; such as official loans, commercial loans, etc. The expenditures are associated with debt payments, with the fixed and the variable cost of the corporation.

The principal aim of this area is the economic balance sheet of the corporation, i.e., it is responsible for the distribution of the resources to the remaining areas, for the repayment of the debt and for obtaining profits for the shareholders.

2.2.2 - **Materials Area**

Is the area responsible for managing the purchase of the materials required for the execution of maintenance and/or repair of the generator units. As a support activity it fulfills a fundamental role, either in the operation or in the finances. An inadequate management in this area can lead to the excess or lack of stocks, the first causing unnecessary expenses and the second causing delays in the placement into service of the machines under maintenance or repair.

3 - COMPUTER IMPLEMENTATION

The proposed model was implemented through the technique of System Dynamics to permit analysis of the aims of the technical areas of the corporation. The results associated with the project area and the global results are presented as follows:

3.1. - <u>**Analysis of the Aim of the Project Area**</u>

For this case, it is assumed that the project sector is formed by a fixed team, equivalent to 30 university graduates, working 8 hours per day, 12 months of the year. The project requests occur in a constant manner, demanding the Man-hours/month of the variable *Demand for services* in Table 1. Supposing that the aim of the area is to conclude the year without any delay in the projects, it is desirable to analyse the policies and costs to be anticipated in this área.

In this way, the analysis is reduced to comparing the *Demand for services* with the *Own resources.* Should the result be negative, action is taken to determine the resources required to contract outside services. Table 1 also presents the balance of service, the variable *Forecast of outside services* (accumulated value in Man-hours) and the additional cost necessary to attain the objective (accumulated value in US$), the variable *Additional Costs*, considering the cost of Man-hours for the outside services to be 30 US$/hour.

Table 1 - Variables and Results of the Project Area

Month	1	2	3	4	5	6	7	8	9	10	11	12
Demand for services	6500	3400	5700	4850	6020	5340	5640	6800	7200	5850	3600	4670
Own resources	5040	5040	5040	5040	5040	5040	5040	5040	5040	5040	5040	5040
Forecast of outside service	1460	0	480	290	1270	1570	2170	3930	6090	6900	5460	5090
Additiona costs x 1000	43,8	0	14,4	8,7	38,1	47,1	65,1	117,9	182,7	207,0	163,8	152,7

From Table 1 it can be concluded that the area will have a deficit of 5090 Man-hours at the end of the period and that to avoid this déficit requires additional resources of the order of US$ 152700.
In the following example, it is assumed that the area receives a prompt order of 20000 Man-hours in the fifth month, with a conclusion term of 4 months, apart from what has to be carried out by the staff. The management desires to analyse the strategies that will allow the sector to attain the end of the period with the aim of a zero service backlog. In this case the problem is reduced to determining the number of people and the best period to contract the services of outsiders. This problem was resolved with the support of the System Dynamics model constructed on the basis of the diagram of Figure 1. Table 2 summarizes the results of the model.

Table 2 - Variables and Results of the Project Area

Month	1	2	3	4	5	6	7	8	9	10	11	12
Demand for services	6500	3400	5700	4850	26020	5340	5640	6800	7200	5850	3600	4670
Own resources	5040	5040	5040	5040	5040	5040	5040	5040	5040	5040	5040	5040
Contracted outside	0	0	0	0	2856	3192	3192	3192	3192	3192	3192	3192
Availability for project	-1460	180	-480	-290	-18414	-15522	-12930	-11498	-10466	-8084	-3452	110
Addition.Costs x 1000	0	0	0	0	85,58	181,4	277,2	373,0	468,7	564,5	660,2	756,0

Upon consideration of the modality of contracting in the market for services, the conclusion is reached that the best alternative is to contract a more or less fixed number over the longest possible period. In Table 2 it can be seen that the best alternative for the area is to contract seventeen (17) people at the start of the fifth period and to reinforce with two people more from the start of the sixth period. This estimate for *Contracted outside*, plus *Own resources* for the area will permit the project sector to reach the end of the period with zero service backlog, verified through the variable *Availability for project.* The resources necessary for this alternative are evaluated at US$ 756000.

3.2 - **Analysis of the Targets of Remaining Technical Areas**

In a similar manner to the analysis of the project area each of the areas can be analysed individually. This can be effected by isolating from the global program the variable that permits visualising the desidered behaviour. Table 3 provide the variables that will permit the analysis of the targets for the three technical areas.

Table 3 - Variables that Represent the Targets of the Technical Areas

Area	Project	Operation	Maintenance

Variable	Availability for the project	Discrepancy production-demand	Availability for maintenance

3.3 - **Analysis of Global Strategies**

For an analysis at the management level, it can be established that the aim of the corporation is to attain a favourable economic result at the end of a determined period. Therefore, a stock variable was created that accumulates the economic result; the rate of increase of this stock variable will be the *Gross Income* and its rate of decrease the *Expenditures*.

The *Gross Income*, in its turn, has a **rate of increase** constituted by the *Energy Demand* times the *Cost of Energy*, plus *External Loans*, and a **rate of decrease** constituted by the *Purchase of Energy* from third parties and the *Payment of Fines,* caused by indexes of performance inferior to the ones that were contracted. As the *Expenditures* increase according to a **rate** formed by the *Fixed Costs,* that include the resources from the different areas, the *Additional Resources* and the costs associated with the *Debt Amortisation*.

Depending on the economic results, the management of the corporation may apply strategies that strive to improve these results. These strategies may include, for example: reduction of the supply, price increase, delay or anticipation of maintenance, cuts in the budgets of the areas, delay in the repayment of the debt, loans from banking institutions, etc. Table 4 summarizes the results of two alternatives for analysis.

3.3.1 - **Basic Economic Results**

This alternative determines in sequence, the power per unit, the power generated by the station, the maintenace scheme, the indexes of performance, the income from operation, the expeditures and the economic result, in relation to each hydrological condition and for the twelves periods of analysis. Table 4 presents these results.

Table 4 - Economics Results

	Basic Economic Result (US$/period)			**Economic Result caused by Multiple Strategies (US$/period)**		
Period	Hydrology high	Hydrology normal	Hydrology low	Hydrology high	Hydrology normal	Hydrology low
1	-3.498.752,30	-3.498.752,30	-3.498.752,30	-6.275.355,60	-6.275.355,60	179.274,90
2	-3.657.304,75	-3.657.304,75	-3.657.304,75	-10.619.126,8	-10.619.126,8	-484.997,19
3	-2.155.545,97	-2.155.545,97	-2.155.545,97	-13.031.313,6	-13.031.313,6	-1.992.816.29
4	-653.787,19	-653.787,19	-653.787,19	-15.443.500,4	-15.443.500,4	-3.500.635,39
5	-7.344.873,99	-7.344.873,99	-194.453.307,1	-11.460.716,4	-11.460.716,4	-2.359.054,52
6	-17.175.976,1	-17.175.976,1	-717.969.627,1	-6.693.065,10	-6.693.065,10	-11.203.963,72
7	-17.934.754,7	-17.934.754,7	-1.286.408.197	-1.126.274,12	-1.126.274,12	-22.133.252,72
8	-18.693.533,3	-18.693.533,3	-1.840.063.707	4.440.516,86	4.440.516,86	-31.913.841,22
9	-14.185.074,9	-14.185.074,9	-2.117.966.427	8.894.223.71	8.894.223.71	-34.668.076,72
10	-20.155.629,6	-20.155.629,6	-2.316.677.787	12.709.435,62	12.709.435,62	-33.938.240,72

11	-26.335.837,2	-26.335.837,2	-2.612.161.547	16.587.966,35	16.587.966,35	-38.431.745,82
12	-21.506.621,7	-21.506.621,7	-2.883.415.787	21.355.617,69	21.355.617,69	-40.384.333,92

Various conclusions can be drawn from the basic result, among the principal ones can be mentioned: that the result of the corporation is unsatisfactory for the high and normal hydrological conditions, and that it is inadmissible for the low hydrological condition. The principal cause of the unsatisfactory condition is associated to the index of the performance of the service (LOLP); this index assume values close to or equal to unitary, with which the fine reaches extremely high values (1500 US$/MW).

The corporate strategy should be directed towards improving this index of performance. In the following item, new economic results are determined taking into consideration multiple strategies.

3.3.2- **Economic Results from Multiple Strategies**

The strategies adopted in this alternative are the following: demand is reduced by 10 %; the fixed cost are increased 20 %; the sales price is increased 10 %, the maintenance of all the units is perfomed in the first four periods. Apart from this, it was chosen to purchase an average de 200 MW of energy from an outside system in all periods at a cost of 20 US$/MW/h, during the period of low water inflows. Table 4 also presents these results.

The principal conclusion for this alternative are the following: the results for high and normal hydrological conditions are considered satisfactory. The result for the low hydrological condition is unsatisfactory and requires additional strategies to render it satisfactory, such as: increase in price, the purchase of a greater quantity of energy from the external systems, reduction of the fixed or variable costs, etc.

4 - CONCLUSIONS

The present study presented a model suitable for the strategic planning of a hydroelectric generation utility. To this end, a conceptual analysis was made of the different variables and processes that interact to form the global model and, the results obtained with the help of the System Dynamics technique were presented sequentially.

The model strives to equip the electric generation utilities with a tool to assist in the taking of decisions, both at the level of the individual áreas as within the strategic planning of the corporation as a whole.

The results presented indicate some of the possibilities for analysing corporate strategies. Other analysis may be effected within the limits established in the model.

It is worth mentioning the great flexibility of the proposed method, since for the analysis of corporate strategies it is not necessary to directly handle parameters of the technical model; this is done automatically at a different level.

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