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OPTIMAL SCHEDULING OF SUGAR-CANE UTILIZATION AIMING TO MAXIMIZE COGENERATION

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1 Introduction

In the sugar and alcohol production from sugar-cane it is generated an energetical waste, the bagasse, that can be extensively used as fuel in sugar industries as well as in orange juice and soybean oil plants, in cogeneration systems. Bagasse is responsible for around 8% of the total energy offered in the Brazilian energetical context, and its characteristics of price and availability indicate an increase on its demand in short-term. So, it is interesting to increase the generation of bagasse surplus, and for assuring the amount for continous use, it is necessary to analyse the production pattern (sugar/alcohol rate) and production program influence over the waste availability. Those features are not usually considered, so in this paper it is presented a model based on Dynamic Programming to associate them to the maximization of the waste production.

The Dynamic Programming approach, DP, was firstly developed by Bellman about 1955 and it has been acknowledged as a powerful tool in the optimization of a wide variety of situations. Its application is not sophisticated, and it is rather suitable to the development of computer algorithms. The Dynamic Programming received its greatest boost from the 1970's, associated to the widespread of the modern computers' capacity and speed [1].

The optimization problems to which the DP applies are generically called problems of dynamic optimization, problems of variational control or problems of optimization for step wise decision process These problems are characterized by the fact that the decision taken presently will affect the system behavior in the future, in such a way the ideal solution is a sequence of decisions, during a control period, and not only a solution for a certain moment

2 - Application to the Production Planning

The issue of how to allocate the production goals, sugar and alcohol, along the crop period is clearly a problem of step wise decisions, and the decisions affect each other progressively, so it is possible to use the Dynamic Programming The approach suggested in this case has the following parameters

a) System Equations

- k - stage variable - time
- $x(k)$ - state variable - quota-completed fraction, i.e., ground sugar-cane until $\underline{k}$ stage, with respect to the total grinding needed for sugar.
- $u(k)$ - control variable - fraction of the sugar-cane intended to sugar, with respect to the total grinding, during the period from $\underline{k}$ to $(k+1)$.

b) Performance Criterion

The amount of bagasse surplus is adopted, which depends on the system state and control variables. This is a measurement of the energetic surplus

c) Constraints

The final and initial values of the quota equal necessarily 100% and 0%, respectively, and the sugar-cane available in that period can complete only a fraction of the quota. The accomplished values of the quota cannot over and above be decreased

The problem can be more complicated than the formulation used here, involving, among others, details of the storing cost of the products (mainly alcohol) and the trading policy itself.

The bagasse produced by stage for one of the mills depend essentially of the bulk of sugar-cane processed during the period, on the sugar-cane fiber and on the production profile, i.e. the relative bulks of alcohol and sugar production. So, it is possible to estimate the overall bulk of bagasse produced, and with help of simulation models of the industrial process of sugar and alcohol production [2] it is also possible to obtain the surplus of bagasse. One clearly sees the great usefulness of a simulation model for planning, allowing to assess the bagasse surplus levels under sundry operational situations.

The sugar-cane features and the expected production bulk are values estimated by the agricultural sector staff with a reasonable certainty level. An effort to increase the reliability of these information can tally directly with a better final result in the planning, nonetheless, the model of Dynamic Programming suggested to permit corrections during the crop accomplishment. Whenever casualties are found, at the level of quantity and characteristics of the sugar-cane for each period, or at the level of estimated demand of the end-products, or also at the level of equipment and process, the planning should be done over again, a new optimal path being established. It is recommended even a permanent overhaul and attendance of the mill conditions horizons which may affect its energetic surplus, so that the corrections can be made always in time.

3 - Applications Example

To exemplify the proposed approach, results obtained through a computer model including the simulation model are presented which are applied to a sugar mill in the state of São Paulo, and employing sugar-cane supplying data relative to 1988. During this year, the overall grinding was of 2,738,100 tons of sugar-cane, distributed in each month according to Table 1.

Table 1 Monthly Data of Sugar-Cane Grinding for the Application Example

MONTH	GRINDING (tons)	MONTH	GRINDING (tons)
May	17,540	August	711,120
June	531,330	September	639,400
July	673,360	October	165,450

TS - Ton of Sugar-Cane

By knowing the sugar production performed by this mill, of 1,025,440 sacks of 50 kg and by adopting an average productivity of 106.4 kg of sugar per ton of sugar-cane, one has the total of sugar-cane needed just for sugar manufacturing, which equals 951,800 tons. From these data the problem initially proposed can be presented again: To allocate the sugar grinding within the sugar-cane supplying program, given in Table 1, looking for maximum production of surplus bagasse.

From design and operational parameters of the extraction systems and equipments, juice treatment and sugar/alcohol production, weighted through a balance of the sugar flows and associated to the energy-converters simulation-models, as boilers and turbines, a simulation overall program of the industry sector was developed [3]. By applying the actual values of the mill considered, figure 1 was obtained, so allowing to apply the Dynamic Programming Model.

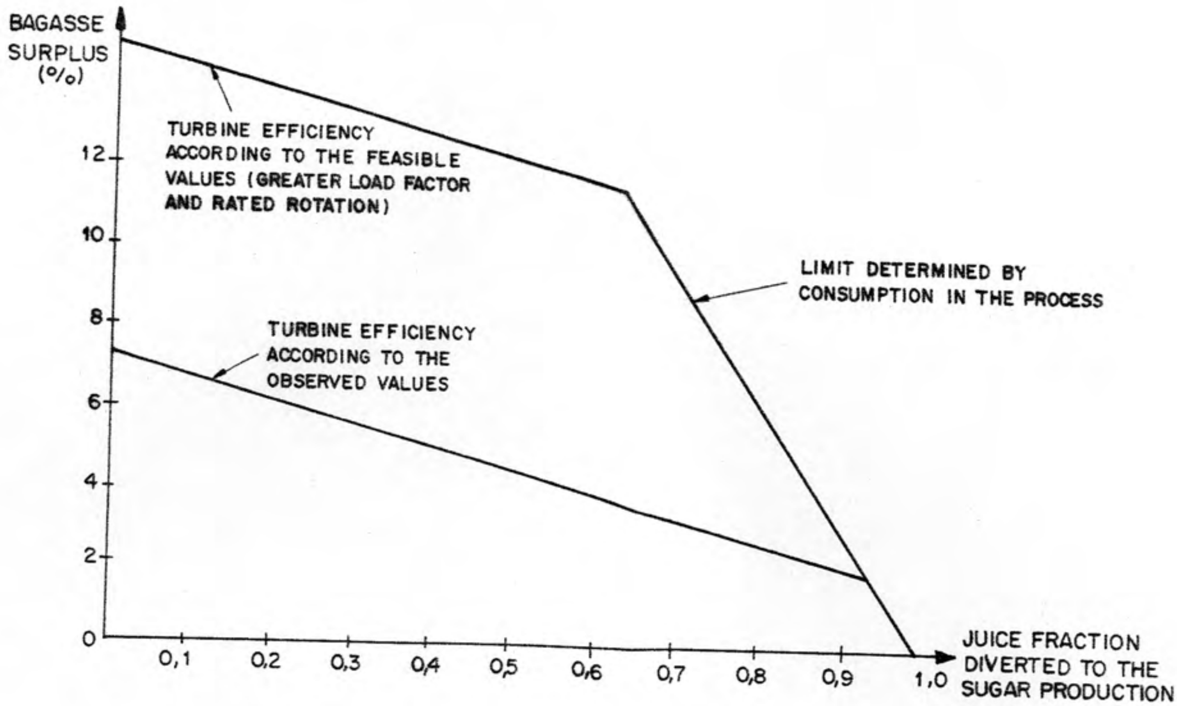

Figure 1: Bagasse Surplus in Function of the Relative Production Alcohol/Sugar.

For greater relevance with industrial reality an additional constraint was added in this example, which is associated to the admissible sugar grinding in the period, due to the capacity limitations in the manufacturing equipments. The value styled to this constraint was of 350,000 tons by period. Figure 2 shows the several optimum paths obtained in this example. In this case the discretization employed was of 10%.

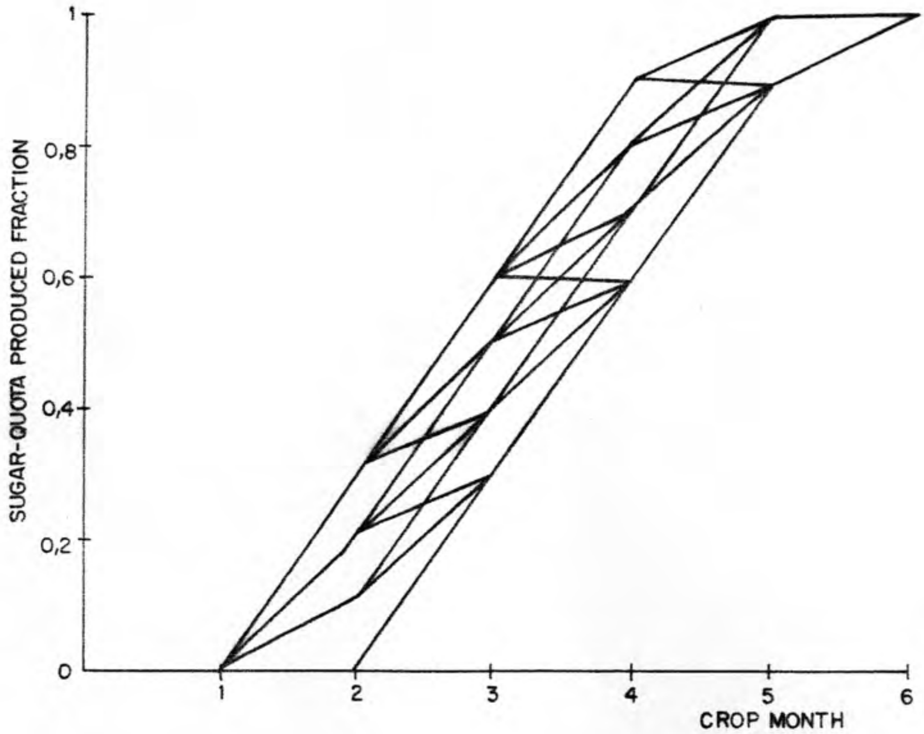

Figure 2: Optimal Paths in the Crop Planning

It is interesting to notice that for the mill example, the turbine efficiency does not affect the optimum path, but only the final surplus of bagasse. For turbines in ideal conditions of load and rotations, the bagasse surplus at the end of the crop would be 86,350 tons, corresponding to 12.6% of the total bagasse produced. For turbines in the actual conditions of operation such surplus would be 35,680 tons, relative to 5.2% of the total. The a presence of several optimal paths is due to the linearity of the relationship between the bagasse surplus and the production profile, assumed on the onset constant with time

When it is considered that the bagasse surplus varies with time, for a given production relationship, in function of the wearing of mechanical equipments and incrustations in the thermal equipments, the solution obtained has just one optimal path, as shown in figure 3, as a discretization of 5%.

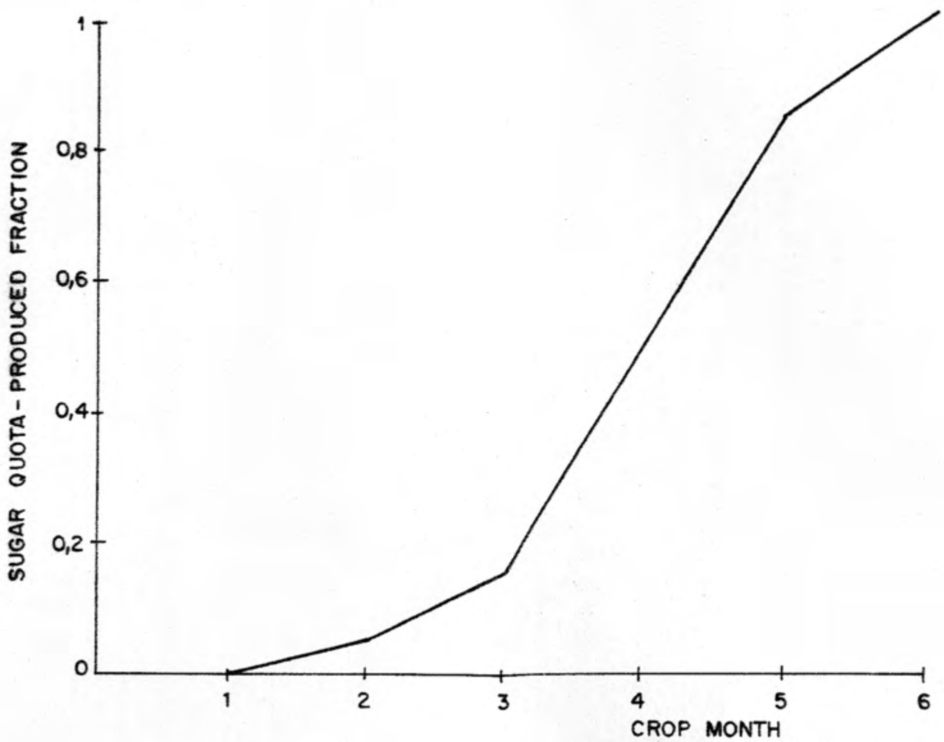

Figure 3. Optimal Path for the Crop Planning in Similar Situation to the Previous Figure, by Considering a 10% Cut Down in the Generation of Bagasse Surplus Along the Crop.

It is worth noting that this last result delivers the goods. If the bagasse surplus is larger in the crop beginning and if larger alcohol bulks, relatively to sugar, also mean larger bagasse surplus, it is reasonable to shift, within grinding limitations, the sugar production to the end of the crop. Table 2 details the previous figure.

Table 2: Monthly Data of the Crop Plan Regarding Fall in the Bagasse Surplus Along the Crop (Referred to the Previous Plot).

MONTH (STAGE)	GRIDING FOR SUGAR (1000 tons)	SUGAR QUOTA-COMPLETED FRACTION		BAGASSE PRODUCTION ON MONTH (1000 tons)	OVERALL PRODUCTION OF BAGASSE (1000 tons)
		MONTHS's BEGINNING	MONTH's END		
May (1)	0.00	0.00	0.00	0.31	0.31
June (2)	47.59	0.00	0.05	8.80	9.11
July (3)	95.18	0.05	0.15	10.43	19.54
Aug (4)	333.13	0.15	0.50	7.50	17.04
Sept (5)	333.13	0.50	0.85	6.14	33.18
Oct (6)	142.77	0.80	1.00	0.79	33.97

4 - Final Remarks

Other conditionings and contour functions can be included in the Dynamic Programming model without any greater difficulties. For instance, periodical variations of the fiber, the sugar-cane POL, bagasse moisture, etc. can be considered. Another interesting line to be exploited would be the probabilistic approaching to the supplying and the characteristics of the sugar cane. In this case the optimal path is defined within a range of desirable reliance.

In short, it is believed that this program, since it is well suited to the particular situation of each mill, may come in handy in a fast and simple way so as to help the determination and correction of the production plan energetically more recommendable.

5 - References

[1] Dreyfus, S.e. and Law, A.M.: "The ARt and the Theory of Dynamic Programming" - Academic Press - New York - 1977

[2] Nogueira, L.A.H. and Macedo, I.C.: "Simulação Computacional do Fluxo Energético na Indústria de Acúcar e Álcool" - (in portuguese) - IV Technical Conference UNCL - Cuba - 1988.

[3] Nogueira, L.A.H.: Análise da Utilização de Energia na Produção de Álcool de Cana de Açúcar" - (in portuguese) - PhD Thesis - UNICAMP - Brazil - 1987