Transforming South African Sugarcane Factories to Biorefineries

MISG 2011 – Group
Industry: Steve Davis + 1

.

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Overview

1. Introduction
2. The model problem
3. Direct Solution
4. Sensitivity
5. Stochastic simulation
6. Conclusion

Description of the problem 1

- Sugar refinery is self-sufficient in energy - recycles many products
- Supplies sugar to domestic and international markets
- Produces mainly sugar, but also has many by-products
- **MISG:** Can profitability be increased by alternative use of by-products make ethanol, bio-polymers, generate power, ...?
- **MISG:** How can this decision be made?

Description of the problem 2

- To consider everything a massive optimization AND modelling problem
- Group decided to create a framework for future implementation
- Decided to use “juice” to consider various possible uses
- This can be applied in principle to other processes

The model problem

The "juice" can be sub-divided in the following ways, giving three possible products with different values, costs, etc.

$$\text{Sugarcane} \rightarrow \text{Extraction} \rightarrow \text{Juice} \rightarrow \begin{cases} \text{Sugar} \\ \text{Ethanol} \\ \text{Biopolymer} \end{cases} \rightarrow \ldots$$

Aim: Find the combination of proportions of each product that will maximize the profit

Mathematical Model

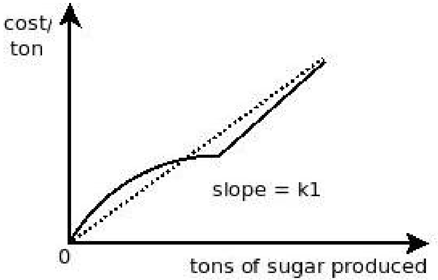
- Set up a model for the value of each product including costs and sale price, e.g.

$$V_k = A_k \left(P_k - C(A_k)\right)$$

  - A_k=amount of product k,
  - P_k=price of product k,
  - $C(A_k)$=cost function for product k - depends on A_k
- Consider different possible cost functions
- Assume constant sale prices
- Optimize profit using various solution procedures

Sugar - from SA Sugar Industry

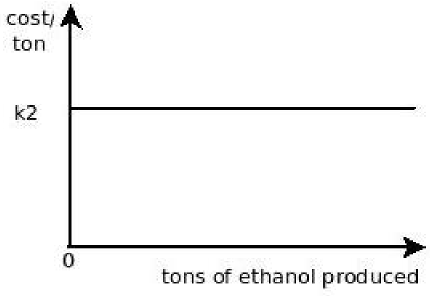
Sugar: Assume a linear growth in cost (with rate k_1) as amount of sugar produced, A_1, increases if P_1 is price of sugar



$$V_1 = A_1(P_1 - k_1 A_1)$$

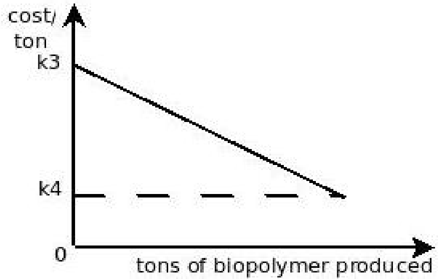
Ethanol - from SA Sugar Industry

Ethanol: Assume a constant cost, k_2, independent of amount produced, A_2. P_2 price of ethanol



$$V_2 = A_2(P_2 - k_2)$$

Biopolymer: Assume a constant set-up cost, k_3, then decreasing costs (at rate k_4) as more is made. A_3 amount of biopolymer, P_2 price of biopolymer



$$V_3 = A_3(P_3 - (k_3 - k_4)A_3 - k_3)$$

Mathematical formulation

$$\max \quad V = V_1 + V_2 + V_3$$

$$\text{s.t} \quad A_1 + A_2 + A_3 = 1$$
$$A_1 \geq 0; A_2 \geq 0; A_3 \geq 0$$

where

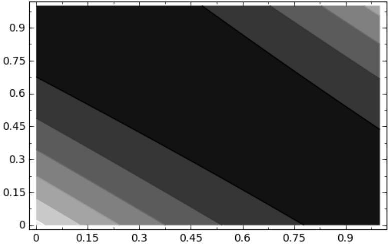
$$V_1 = A_1(P_1 - k_1 A_1)$$
$$V_2 = A_2(P_2 - k_2)$$
$$V_3 = A_3(P_3 - (k_3 - k_4)A_3 - k_3$$

Can reduce to 2D problem by noting $A_3 = 1 - A_1 - A_2$ and substitute.

Mathematical solution

Using some data of the prices and the costs of production from the industry

- Analytical solution:
  Take partial derivatives wrt $A_k, k = 1, 2$ set to zero
  check boundaries of feasible region



- Numerical solution using MATLAB: $A_1 = 0.0; A_2 = 0.0; A_3 = 1.0$

Sensitivity Analysis

- Given that the different prices on the market are not fixed, we were interested in how can this change affects the benefit V.
- Vary P_3 and solve using MATLAB

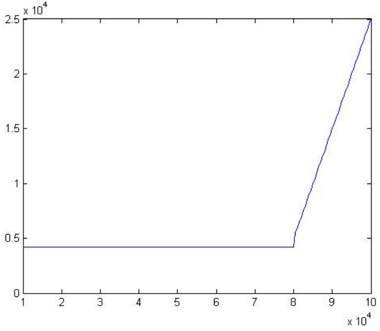


Figure: The Evolution of V as P_3 is changing

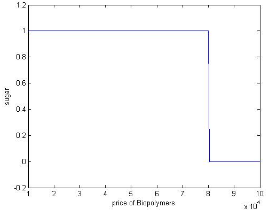


Figure: Evolution of A_1 as P_3 changes

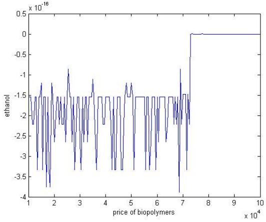


Figure: Evolution of A_2 as P_3 changes

Simulation of the Evolution of the Benefit over 25 year

Let's assume that the variation of the price of biopolymers on the market is normally distributed

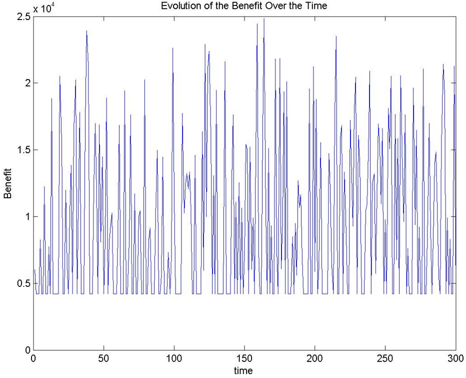


Figure: Evolution of the Benefit over the time

Decision Guide

- Now consider volatility of all parameters - production cost & market price
- Get different values of the benefit V and it's standard deviation
- enable the decision makers to evaluate the risk of the product choice

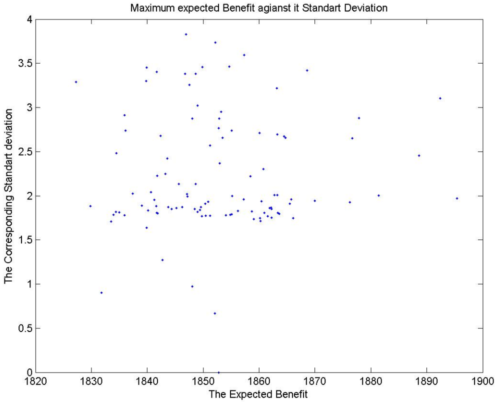


Figure: Evolution of the Benefit over the time

Some Comments

All the results presented previously have been chosen by us, since there were not enough data provided to us by the industry, we simulated using our own data. However with real data, the principle will be same.

Concluding Remarks

- A very complicated problem to solve all of it.
- A simple "model" problem was posed to provide the framework for future decision-making
- The model was solved directly
- Sensitivity to price variation was considered
- Stochastic simulations over an extended period provide a measure of risk
- A more sophisticated model could be built including all possible products and services
- There is still room for more detailed modelling within each product choice to better quantify the structures.