

Crop Planning System for tilling optimisation.

James Cunha Werner (wernerjc@sbu.ac.uk)

Terence C. Fogarty (fogarttc@sbu.ac.uk)

SCISM
South Bank University
103 Borough Road
London SE1 0AA

This paper describes the optimisation project developed in Brazil through the implantation of Sun Sparc Stations centralizing the crop planning system to support decisions about the date to start harvest, areas to be sampled and cropped, simulation of farming activities during crop and between harvest.

1 Introduction.

Proalcool, the Brazilian Alcohol Program, is indeed the largest program of commercial biomass utilisation for energy production in the world. Despite its current economic difficulties, it presents the well-known environmental benefits, reduction on import expenditures and creation of jobs in rural areas, among other advantages.

Current jobs in sugar-alcohol sector are one million direct jobs in rural area, more indirect/industrial 300,000 jobs in 350 private industrial units and 50,000 sugarcane growers (also private). In São Paulo, there are 500,000 works in the 132 sugar-alcohol plants established in the State. Moreover, investment for the creation of jobs in sugar/alcohol industry is much lower than in other industrial sectors.

Brazilian sugar cane production has reached 320 million tonnes (metric tonnes) in 1998/99 harvesting season. Sugar and alcohol production rose to 18 million tonnes and 14 billion liters respectively, mainly due to increases in agricultural and industrial efficiencies. In São Paulo State, cane production was more than 198 million tonnes, corresponding to 12 million tonnes of sugar and 10 billion liters of alcohol. Sugar cane plantation area is 3.9 million hectares in Brazil and 1.8 million hectares in São Paulo.

All these figures show the important role played by São Paulo State in this agribusiness sector. Also, its productivity is the highest one when compared to other regions; average industrial efficiency is 80,6 liters of alcohol (both anhydrous and hydrated) per tonne of crushed cane, against 78,3 l/tc in Brazil. Moreover, there are industries in the state whose productivity reaches 100 liters of alcohol per tonne of cane (for more information see [1]).

The sugar-cane cultivation is made in areas divided in farms, lots, and blocks (6.000 or more for one company) where canes of several varieties are available depending with climatic, soil, and on the period of the year will reach maximum maturation condition. The main objective is feed mills with an amount of cane limited for its maximum capacity and the best cane available during all harvest with regularity.

To crop the cane, several job fronts are building with agriculture machines, trucks and workers, covering 3600 square kilometres of tilling, producing 20 tons of sugar and 1.200.000 litres of alcohol a day with more than 20.000 workers.

The cane should have an appropriate amount of fibre for a good sugar extraction and cane juice obtained by mills should have the largest possible concentration of sugar, optimising the total production of the industrial process of refined sugar for human consumption and alcohol for engine combustion and chemical applications.

The mill is made by mechanical process of compression, for successive triplets with forced water wash, through where the cane passes and the juice is extracted.

This process is influenced directly by the fibre because:

- If the amount of fibre goes down, the compression of the triplets is hindered by the low amount of solid mass and high juice concentration.
- If the amount of fibre goes up, the accomplished work will be larger and the mill speed will reduce, with sugar loss increase in the fibre.
- Inside of the range where was made the adjustment of the mills, the work accomplished by the triplets will be adapted and the extraction of sugar will be correct.

The process of production of sugar also depends on the juice sugar concentration because if it is low, it will be necessary a great water evaporation to obtain the syrup. The evaporation capacity is associated to the area of the available multi stage pan. It is common to happen a mill stop or reduction, with losses and decrease of the production.

In the alcohol production process, the volume and the concentration of sugar are fermentation limiting factors. Fermentation yeast stops alcohol producing when the concentration arises besides a specific value, and the sugar is consumed in another biochemical processes, decreasing the efficiency significantly.

The software goals are obtain the crop starting date, areas to pre-crop analysis that represent all tilling and selection of crop areas to feed the factory mills with little flotation of its characteristics, maintaining the process without oscillations that increase the losses and reduce the efficiency. Several management activities are support by the software too.

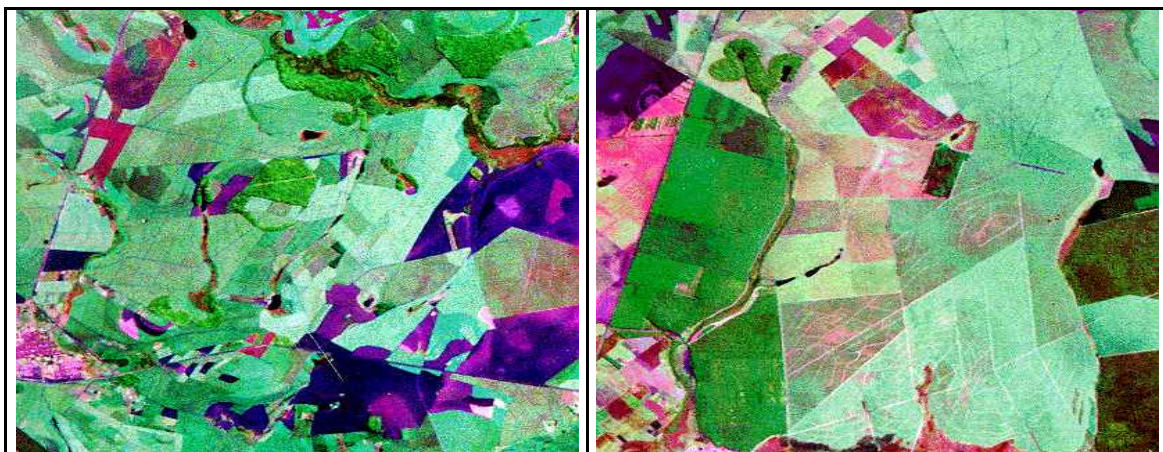


Fig 22 Satellite tilling views, where the colours show the maturation level of each block, with means different sugar concentration.

2 Description of Agricultural Process Optimisation.

The agricultural crop is divided in periods of one week (“Periodo”) to allow a closing comparison between the actual and the simulate one, and to adapt to differences due weather.

A very important result of the program is the determination of crop beginning date and the strategy of fertilizers application. To do a simulation of the crop before its beginning, is necessary to build a database with previous information on the grow up of each variety according to the weather, soil, and manure type of each block available in tilling (or a similar behaviour). With these data, the system models the cane variety development adjusting second order mathematical equations to the experimental grow up points, and adjusting the curves according to the application of the fertilizers.

The software makes the tilling areas selection for crop maximising the sugar production economic function, based on the mathematical model ([2], [3], and [4]):

$$Economic \ Function = \sum_{land} [ATR * Prod * Area]$$

Constraints:

$$minimum \leq \sum_{jobhead} [Area * Prod] \leq maximum \ crop \ for \ each \ job \ front$$

$$minimum \leq \sum_{land} [Area * Prod] \leq maximum \ milling$$

$$Area \leq land \ area$$

where: Prod: cane per hectare productivity; ATR: theoretical recovered sugar; Crop maximum and minimum: crop limit for each job head; Milling maximum and minimum: mill limits.

To apply this model the available farm information feeds the equation assembly routine that generates more than 1200 constraints equations to be solved with modified Simplex method for each job front.

The gain in relation to the traditional derives of the blocks choice methods difference. Traditional choice system take bases more on the agricultural responsible person experience than in mathematical concerns, with choice reflects a result calculated among all the alternatives and combinations that respect the problem restrictions with an performance criteria extreme value.

To obtain the crop beginning its necessary to consider that to transport from tilling to the industry trucks will run on the planting, impossible with a wet soil during rain season (that begins in December in Brazil), due to swamp and damage to the plant. This defines the crop end. The mill capacity defines the cane amount during the crop, and the simulation of crop from different starting dates shows the date with maximum performance (see Fig. 1).

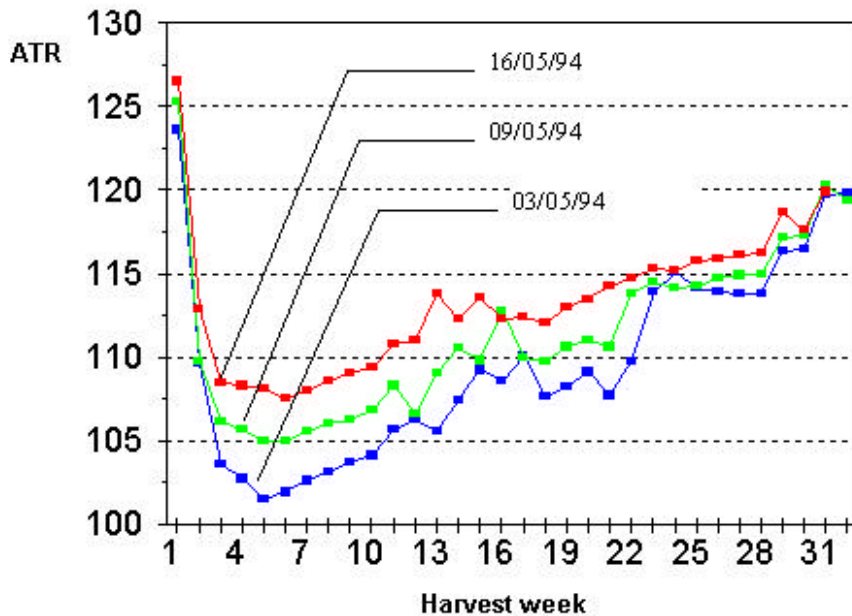


Fig.1: Crop simulation from different beginning date.

March to May is the period of biggest biomass acquisition than later crop begins bigger will be the final result in sugar amount extracted from the juice because the sugarcane will have larger mass and larger concentration of sugar. On the other hand, due the rain effects in transport, it is not possible to accomplish the crop in the period of rains (December to March).

There is a balance point between the increase of the concentration and the decrease of the total amount of mill cane and it is the target to be found by the system.

In Fig. 2 it can be seen that starting after 9/5/94 the results of the crop tend to drop due the total cane amount reduction and before due to immature cane. The optimal start date will be 09/05/94.

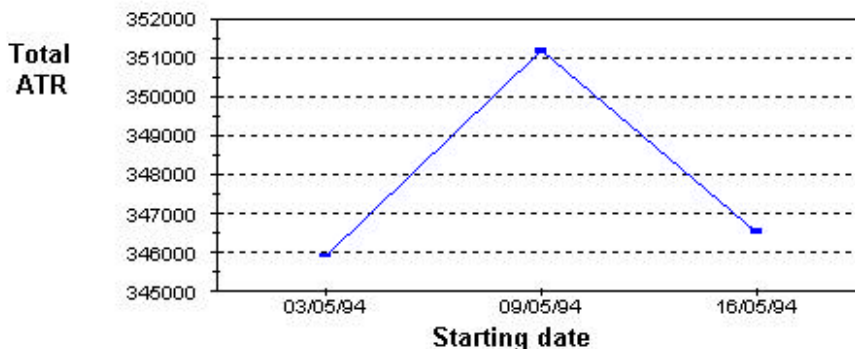


Fig.2: Crop start results with different date.

It can be observed that the final result beginning in 03/05 and 16/05 are practically equal, even so the factory will have to mill more 200.000 tons of cane. Besides the transport and labour costs there are the costs of maintaining the factory operating two weeks more.

The crop beginning 09/05/94 will have a reduction of one week in relation to 03/05 giving a larger result 1.5% and a reduction of the mill of 100.000 tons of cane, that it corresponds more than 1.5 million dollars for crop in a factory of medium load.

Another simulation output is the week by week result of the amount of sugar by cane volume that arrive in the factory from different job fronts, with permits the analysis of the fertilizers application for improvement of the sugar amount.

In Fig.3 the results are presented for the crop of 1994 of the different fronts.

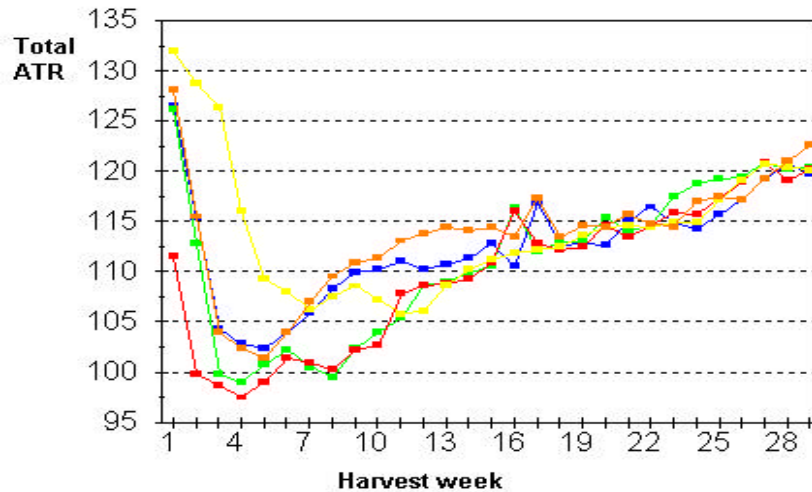


Fig. 3: Simulation results for each different court fronts for 1994 crop.

Fig. 4 shows each value divided by the average and it can be observed for example that the front 3 has a value below the average, with demands fertilizers application in these areas to improve its results.

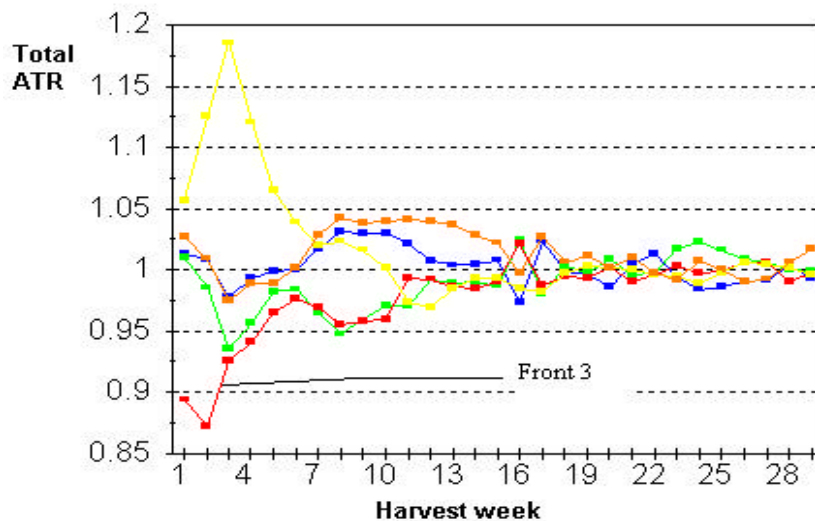


Fig.4: Front comparison against the average (=1).

1 68 13: 50: 4 31/ 1/93 333 124.0

Listing 1: Sample blocks to represent homogeneous areas.

4 Crop selection.

This choice should take into account several factors:

- Feeding continuity of mill, that is, along the whole crop the industry should be fed of cane with the same fibre characteristics without interruptions. A wrong choice can change the fibre with consequent loss of sugar and fall of the amount of mill cane.
- Liberate areas for plantation along the crop.
- Liberate areas for application of alcohol production residue (“Vinhaca”) that is harmful for the springs, but beneficial for the tilling.

The result is presented in a report with the homogeneous areas, the blocks, the last analysis values and the current calculated values of maturation with base in the maturation model and the maximum maturation possible to be reached. For every week of crop the sugar recover average by cane ton by front and the medium value of all fronts are calculated (listing 2).

Usina teste SPSP029 Tue Dec 26 11:21:10
 1995
 Relatorio de Faz/Lot/Qua para corte.
 Folha: 1

Periodo : 1

F	G	FFF	LLL	QQQ	Data	PC	A.Pre	Area	Dis	VAR.	Ton.Cana	Mat
1	56	11:	43:	3	24/	1/93	0.0	10.12	SP71-6163		1062.6	91.1
1	56	11:	43:	2	24/	1/93	0.0	3.61	SP71-6163		379.0	91.1
1	57	13:	49:	19	31/	1/93	0.0	4.87	SP71-6163		511.3	89.9
1	57	13:	49:	18	31/	1/93	0.0	0.89	SP71-6163		93.4	89.9
1	57	12:	5:	10	24/	1/93	0.0	4.89	SP71-6163		513.4	89.9
1	57	12:	2:	1	24/	1/93	0.0	2.77	SP71-6163		290.8	89.9
2	68	23:	20:	4	31/	1/93	0.0	14.78	SP71-6163		1551.9	93.4
2	68	23:	20:	2	31/	1/93	0.0	10.35	SP71-6163		1086.8	93.4
2	68	23:	6:	5	10/	1/93	0.0	0.62	SP71-6163		65.1	93.4
2	68	23:	6:	2	10/	1/93	0.0	8.31	SP71-6163		872.6	93.4
2	68	23:	5:	3	10/	1/93	0.0	5.52	SP71-6163		579.6	93.4
3	2	31:	68:	1	31/	1/93	0.0	2.86	SP70-1143		277.4	94.5
3	4	31:	68:	9	31/	1/93	0.0	4.67	SP70-1143		453.0	94.5
3	4	31:	68:	8	31/	1/93	0.0	2.01	SP70-1143		195.0	94.5
4	140	42:	57:	8	10/	1/93	0.0	10.45	RB72-454		1254.0	100.0
4	140	42:	19:	1	10/	1/93	0.0	15.55	RB72-454		1866.0	100.0
4	149	42:	57:	6	10/	1/93	0.0	5.79	RB72-454		694.8	100.0
4	149	42:	20:	5	10/	1/93	0.0	15.53	RB72-454		1863.6	100.0
5	7	54:	57:	5	31/	1/93	0.0	2.89	SP70-1143		280.3	94.5
5	9	54:	57:	3	31/	1/93	0.0	4.85	SP70-1143		470.4	94.5
5	9	54:	57:	2	31/	1/93	0.0	5.52	SP70-1143		535.4	94.5

Calculos do periodo : 1

“OR for development prize competition”
 2002 IFORS Triennial Conference – Edinburgh/ Scotland July 8-12,2002.

	MAT	MATMax	Prod.	Dist.	A.Disp	Ida	Qua.	Area	Sim.
Ton.Cana									
1	126.4	131.8	111.4	10.34	209.25	341.43	33	170.95	20000
2	126.1	137.6	105.0	16.03	304.10	342.33	39	190.48	20000
3	111.6	123.5	101.2	42.62	241.55	306.00	34	208.68	20000
4	132.0	132.0	120.0	11.82	255.26	354.00	29	166.67	20000
5	128.1	131.1	114.5	17.41	298.24	346.00	46	176.09	18526

Media total do periodo : 1

	MAT	MATMax	Prod.	Dist.	A.Disp	Ida	Qua.	Area	Sim.
Ton.Cana									
	124.9	131.2	110.4	19.64	1308.40	337.95	181	912.86	98526

Listing 2: Crop areas, average result show in graf.5 and 6 as “Simulated”.

In the end of the period the system generates a report with the actual results for analysis and posterior adjustment (listing 3). The calculation of the average is pondered in the same way that in the listing 2 for the simulate values, to allow the comparison of the results.

“OR for development prize competition”
 2002 IFORS Triennial Conference – Edinburgh/ Scotland July 8-12,2002.

Usina teste SPSP100 Wed Dec 27 11:27:31
 1995
 Relatorio de fechamento dos dados de corte. Folha:
 1

Periodo : 1									
FFF	LLL	QQQ	Idade	A.Cortada	dist	prod	ATR	ATRmax	
13: 16:	2	345		17.26	5.00	1432.58	90.05	122.85	
13: 16:	6	352		12.87	5.00	1068.21	90.05	122.85	
13: 17:	1	345		11.53	6.00	956.99	90.05	122.85	
21: 41:	9	465		5.37	10.00	563.85	127.65	137.58	
21: 41:	10	465		1.56	10.00	163.80	127.65	137.58	
21: 41:	12	465		5.90	10.00	619.50	127.65	137.58	
21: 41:	13	465		4.34	10.00	455.70	127.65	137.58	
21: 41:	14	465		2.88	10.00	302.40	127.65	137.58	
21: 80:	2	241		2.94	13.00	217.56	7.36	136.19	
34: 53:	2	394		19.12	56.00	2007.60	85.26	122.58	
34: 53:	3	394		16.94	56.00	1778.70	85.26	122.58	
34: 53:	4	394		5.47	56.00	574.35	75.98	122.58	
34: 53:	5	394		11.59	56.00	1216.95	85.26	122.58	
34: 53:	6	394		10.97	56.00	1151.85	85.26	122.58	
34: 53:	7	394		11.60	56.00	1218.00	85.26	122.58	
34: 53:	8	394		10.57	56.00	1109.85	85.26	122.58	
34: 54:	2	394		13.94	55.00	1463.70	85.26	122.58	
34: 54:	3	394		8.95	55.00	939.75	85.26	122.58	
34: 54:	6	394		3.58	55.00	375.90	85.26	122.58	
42: 59:	6	479		1.82	10.00	218.40	132.00	132.00	
42: 59:	7	479		7.89	10.00	946.80	132.00	132.00	
42: 59:	8	479		8.65	10.00	1038.00	132.00	132.00	
42: 59:	10	479		8.27	10.00	992.40	132.00	132.00	
52: 73:	1	458		24.97	19.00	2996.40	124.39	129.94	
52: 73:	2	458		19.59	19.00	2350.80	124.39	129.94	
52: 73:	3	458		18.92	19.00	2270.40	124.39	129.94	
52: 73:	4	458		14.71	19.00	1765.20	124.39	129.94	
52: 73:	5	458		8.46	19.00	1015.20	124.39	129.94	
52: 74:	1	458		8.59	19.00	1030.80	124.39	129.94	
52: 74:	2	458		25.67	19.00	3080.40	124.39	129.94	
52: 74:	3	458		5.97	19.00	716.40	124.39	129.94	
52: 74:	4	458		18.88	19.00	2265.60	124.39	129.94	
52: 74:	5	458		6.17	19.00	740.40	126.32	129.94	
Media:		413		1420.53	21.05	95.24	104.33	130.73	

Listing 3: Final results for the period, show in the Fig. 5 and 6 as “Actual”.

The largest cause of discrepancies in an agricultural model is in consequences of climatic effects. The pre crop analyses feedback the model and they correct these effects giving reliability to the system in any condition.

In Figs. 5 and 6 the comparative results of a crop are introduced among executed and the simulate values.

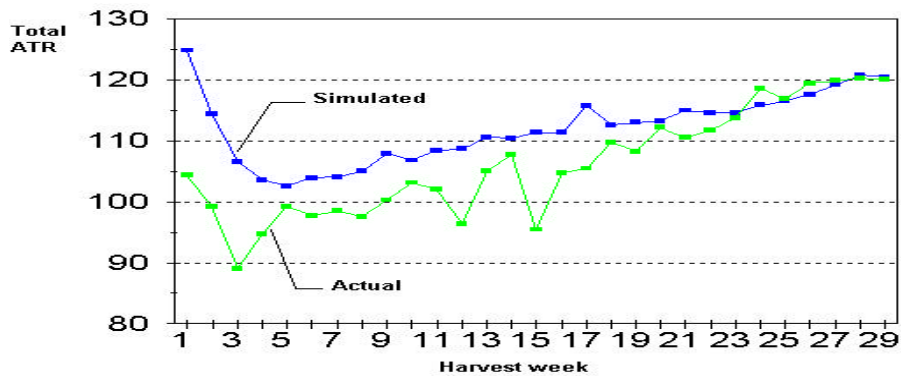


Fig. 5: Total sugar recovered for 1994 harvest. The simulated value is over real showing an evident better result comparing with traditional management.

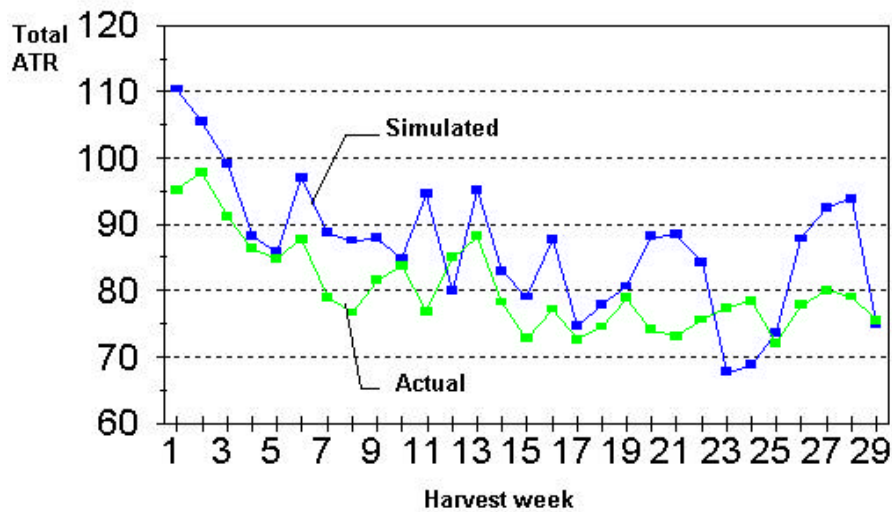


Fig. 6: Hectare production of cane for 1994 harvest.

It can be observed in the figs that the simulate result presents a significant increase of 7.5% in production and 5.5% in sugar recovered in relation to the accomplished in the crop. In a medium load industry (whose revenue is 100 million dollars) this represents 13 million dollars for each harvest.

It is important to remind that these gains don't take into account the economy of the fixed expenses, but are consequence of the improvement of the resources (cane). The juice with more sugar will have less water, and smaller final cost of processing (evaporation process).

5 Pos crop analysis and scaling.

In the industry samples are collected for fibre analysis and sugar concentration and the amount of cane coming of each block is calculated. This information is used for verification of the production forecast, amount of sugar of each block, payment of the vendors, and for model parameters update.

Conclusion and future work.

The application in a Brazilian cane industry showed significant results that agreed with the responsible persons expectation for the crop in the company, with an adherence of more than 90% of the values, but there are critic points without solution using OR.

A system critic point is the maturation curves model quality. In the current work there were adjusted polynomials of second degree, that doesn't take into account real climatic harvest situation. Using the genetic programming ([5] and [6]) will be possible to obtain models that take into account rains volume in growth cane period, supplying more accuracy results.

Other point to be considered is the bottleneck due the transport systems, labour and agricultural equipment allocation that were not considered in the mathematical model and its solution must be adapted due the limitations of transferring infrastructure cost among the blocks, justifying sometimes a premature block crop to avoid to come back for the same place to crop a single block.

The future work will be the application of genetic algorithm ([5] and [7]) and genetic programming to find a complete solution for the problem, with integrates the following point of view:

1. Agriculture equipment allocation into the job fronts with least moves between blocks in the same day.
2. Transport allocation in each work front with minimising queues in the industry entrance and in the tilling.
3. Labour allocation into the work fronts with least moves between blocks in the same day.
4. Best blocks crop selection with maximum sugar concentration.

This is a multi objective problem with is solvable with genetic techniques, with will find the best solution available, trying to respect all constraints at the same time, if possible with the introduction of punishment factor into the performance index for solutions with disagree with constraints.

The results of this paper were applied into Sugar and Alcohol companies of Sao Paulo/Brazil, and its improvement is part of the project “Genetic Control application in real world complex problems”, with consists in the application of artificial intelligence thesis ([8]) to real worlds problems with benefit in medicine, pharmacology, finance, manufacturing, engineering, logistics, and industry areas, supported by South Bank University.

References:

- [1] Coelho,S.T.; The current situation of PROALCOOL the Brazilian Alcohol Program;
http://www.cenbio.org.br/doc_port5.html
- [2] R.Bronson, Schaum's outline of theory and problems of operations research, McGraw Hill
- [3] mscmga.ms.ic.ac.uk/jeb/OR/contents.html
- [4] www.estudio.fc.ul.pt/tutoriais.htm
- [5] HOLLAND,J.H. “*Adaptation in natural and artificial systems: na introductory analysis with applications to biology, control and artificial intelligence.*” Cambridge: Cambridge press 1992 reedição 1975.
- [6] KOZA,J.R. “*Genetic programming: On the programming of computers by means of natural selection.*” Cambridge,Mass.: MIT Press, 1992.
- [7] GOLDBERG,D.E. “*Genetic Algorithms in Search, Optimisation, and Machine Learning.*” Reading,Mass.: Addison-Wheesley, 1989.

“OR for development prize competition”

2002 IFORS Triennial Conference – Edinburgh/ Scotland July 8-12,2002.

- [8] Werner,J.C.; “*Active noise control in ducts using genetic algorithm*” PhD. Thesis - São Paulo University- São Paulo -Brazil-1999.