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PLANNING TRANSPORTS OF SUGAR CANE IN CUBA

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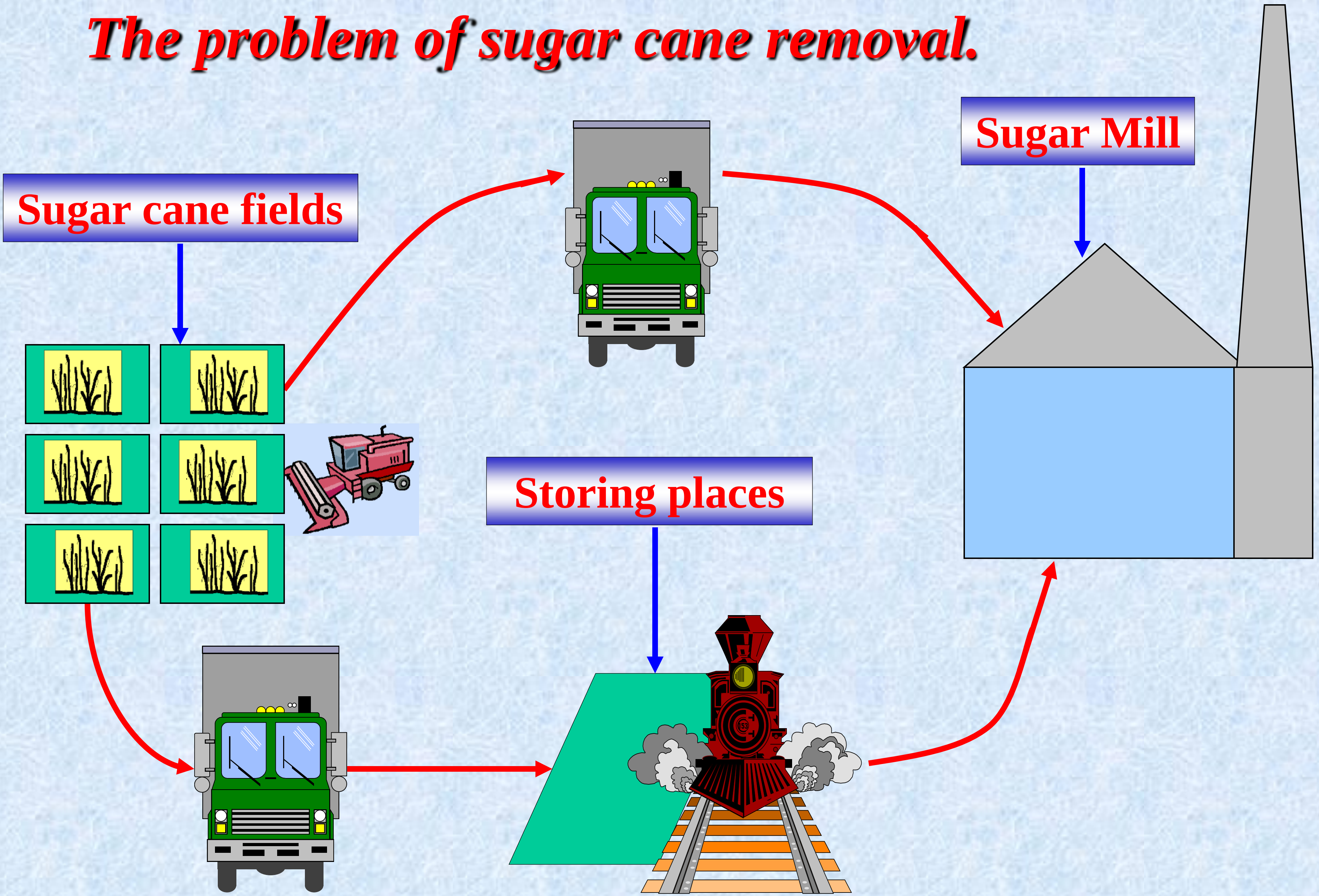
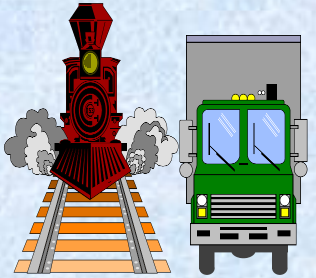
The problem of sugar cane removal.



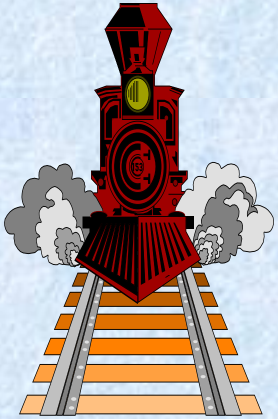
1. Aspects to keep in mind



- Means involved in sugar cane transportation
- Particular technical-economic characteristics
- Two alternatives:
  - Direct transportation to the swing-bolster (automotive)
  - Combined transportation (automotive&rail).

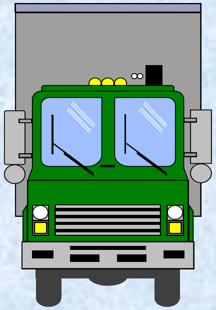
Rail transportation

- Advantages
  - It acts as a storage room of cut cane.
  - The transportation cost per @ is low.
  - It is optional
- Disadvantages
  - It goes against the cane freshness



Automotive transportation

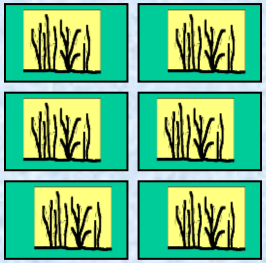
- Advantages
  - It benefits the cane freshness.



- Disadvantages
  - The transportation cost per @ is higher
  - It is necessary

An additional aspect

- The supply of reapers to the cane



  - Effect on quality
  - Effect on time to harvest and process the cane

2. Formulation of the problem

- Variables: $X_{i,j,k,l,m}$

- Restrictions:

$$g_1 (X_{i,j,k,l,m}) \leq b_1$$
$$g_2 (X_{i,j,k,l,m}) \geq b_2$$

- Objective function:

$$\text{mín } C(X_{i,j,k,l,m})$$

2.1 Variables ($X_{i,j,k,l,m}$)

- Origins: i=1,…,7
  - Three Storing places i=1,…,3
  - Four fields i=4,…,7

- Destinations: j=1,…,4
  - The sugar mill j=1
  - Three Storing places j=2,…,4

- Transportation means: k=1,2,3
  - Rail k=1
  - Zil 130 C/R k=2
  - KAMAZ 53212 k=3

2.1 Variables ($X_{i,j,k,l,m}$)- cont.-

- Type of cutting: l=1,…,7
  - Indifferent for rail transportation l=1
  - Mechanical harvesting l=2,3
  - Manual cutting l=4

- Hour: m=1,…,10
  - Possibility of combined transportation m=1,…,10
  - Only rail transportation m=10,…,24

- Number of days (one as example)

TOTAL # of variables: 4*4*3*2+3 =99 per hour

2.2 Restrictions

- Field’s production of cane
- Harvesting capacity by each mean of cutting
- Cane demand of the sugar mill
- Capacity of storing places
- Equality in amount of cane arriving and leaving
- Capacity of transportation

2.2.1 Restrictions of sugar cane fields capacity (in @).

Sugar cane fields capacity (K_i) is as follows: field # 1= 120000 @, field # 2= 180000 @, field # 3= 500000 @ and field # 4= 160000 @.

s.t. # i: Field # i,

$$\sum_{j=1}^{4}\sum_{k=2}^{3}\sum_{l=2}^{4}\sum_{m=1}^{10} X_{i,j,k,l,m} \le K_i \qquad i=1,\ldots,4$$

2.2 Restrictions

- Field’s production of cane
- Harvesting capacity by each mean of cutting
- Cane demand of the sugar mill
- Capacity of storing places
- Equality in amount of cane arriving and leaving
- Capacity of transportation

2.2.2. Restrictions of cutting means (in @ /h).

Sugar cane harvesting is carried out with harvesting machines (in number of 2) and manually with a group of sugar cane cutters. The production of each harvesting machine is 18000 @ /h and using manual cutting 10000 @ /h.

s.t. # 5 to # 24: Mechanical cutting with the group of harvesting machines # 1 and #2 (l = 2,3).

$$\sum_{i=4}^{7}\sum_{j=1}^{4}\sum_{k=2}^{3} X_{i,j,k,l,m} \leq 18000 \qquad m = 1,2,\ldots,10;\ l = 2,3$$

s.t. # 25 to #34: Manual cutting (l = 4).

$$\sum_{i=4}^{7}\sum_{j=1}^{4}\sum_{k=2}^{3} X_{i,j,k,4,m} \leq 10000 \qquad m = 1,2,\ldots,10$$

2.2 Restrictions

- Field's production of cane
- Harvesting capacity by each mean of cutting
- Cane demand of the sugar mill
- Capacity of storing places
- Equality in amount of cane arriving and leaving
- Capacity of transportation

2.2.3. Sugar mill supply.

One of the most important restrictions is the sugar mill supply, which can only process 12500 @ of cane in a hour.

s.t. # 35 to #44: Maximum processing capacity of the sugar mill in a working hour with direct transportation (j = 1).

$$\sum_{i=4}^{7}\sum_{k=2}^{3}\sum_{l=2}^{4} X_{i,1,k,l,m} \leq 12500 \qquad m = 1,\ldots,10$$

To get better indexes of quality in the sugar produced, direct transportation is allowed to be used, establishing an amount of sugar cane that as minimum is supplied to the sugar mill in each hour of work, in this case 10000 @.

s.t. # 45 to #54: Minimal demand of the sugar mill in a working hour with direct transportation (j = 1).

$$\sum_{i=4}^{7}\sum_{k=2}^{3}\sum_{l=2}^{4} X_{i,1,k,l,m} \geq 10000 \qquad m = 1,\ldots,10$$

2.2 Restrictions

- Field’s production of cane
- Harvesting capacity by each mean of cutting
- Cane demand of the sugar mill
- Capacity of storing places
- Equality in amount of cane arriving and leaving
- Capacity of transportation

2.2.4. Supply to the storing places.

s.t. # 55 to #84: Supply to the storage place # 1, #2 and #3 in the first to ten working hours (*j* = 2,3,4).

$$\sum_{i=4}^{7}\sum_{k=2}^{3}\sum_{l=2}^{4} X_{i,2,k,l,1} \leq 6000 \qquad m = 1,2,\ldots,10,\ j = 2,3,4$$

2.2 Restrictions

- Field’s production of cane
- Harvesting capacity by each mean of cutting
- Cane demand of the sugar mill
- Capacity of storing places
- Equality in amount of cane arriving and leaving
- Capacity of transportation

2.2.5. Equality in the amount of sugar cane arriving and leaving from the storing place.

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s.t. # 85 to #114: Correspondence in the storage place # 1,#2 and #3 (j = 2,3,4).

$$X_{1,1,1,1,m} - \sum_{i=4}^{7} \sum_{k=2}^{3} \sum_{l=2}^{4} X_{i,j,k,l,m} = 0 \qquad m = 1,2,\ldots,10, \; j = 2,3,4$$

2.2 Restrictions

- Field’s production of cane
- Harvesting capacity by each mean of cutting
- Cane demand of the sugar mill
- Capacity of storing places
- Equality in amount of cane arriving and leaving
- Capacity of transportation

2.2.6. Restrictions of the transportation means.

$$CR_{i,j,k,l} = \frac{D_{i.j} \cdot \left(\frac{1}{Vcc_k} + \frac{1}{Vsc_k} \right) + Tc_{k,l}}{Cc_k}$$

Where:

$CR_{i,j,k,l}$: Variable coefficient $X_{i,j,k,l,m}$ in capacity restriction of the transportation means. This coefficient is indifferent to the value of *m* (hour).

$D_{i,j}$: Distances from the origin *i*, to the destination *j*.

Vcc_k: Displacement velocity of transportation means *k*, with load.

Vsc_k: Displacement velocity of transportation means *k*, without load.

$Tc_{k,l}$: Waiting time of transportation means *k*, with the kind of cutting *l*.

Cc_k: Loading capacity of transportation means *k*.

Transport means	Speed (km/h)		Total waiting time (h)		Capacity of load (@)	Quantity of means
	With load	Without load	Manual cut	Mechanized cut		
ZIL 130 C/R	20,5	40	0,55	0,333	950	18
KAMAZ 52212	19	35	0,65	0,4167	2000	6

Origin / Destination	SP # 1 (i=1)	SP # 2 (i=2)	SP # 3 (i=3)	Field 1 (i=4)	Field 2 (i=5)	Field 3 (i=6)	Field 4 (i=7)
Sugar mill (i=1)	3	4	4	3	6	1	5
SP 1 (i=2)	0	---	---	2	9	4	3
SP 2 (i=3)	---	0	---	5	10	3	3
SP 3 (i=4)	---	---	0	5	2	5	9

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s.t. # 115 to #124: ZIL 130 CR (k = 2).

$$\sum_{i=4}^{7}\sum_{j=1}^{4}\sum_{l=2}^{4} CR_{i,j,2,l} \cdot X_{i,j,2,l,m} \le 18 \qquad m = 1,...,10$$

s.t. # 125 to #134: KAMAZ 53212 (k = 3).

$$\sum_{i=4}^{7}\sum_{j=1}^{4}\sum_{l=2}^{4} CR_{i,j,3,l} \cdot X_{i,j,3,l,10} \le 6 \qquad m = 1,...,10$$

2.2.7. Sugar mill supply per day.

s.t. # 135: Maximum demand of the sugar mill in a working day (j = 1).

$$\sum_{i=1}^{3}\sum_{m=1}^{10} X_{i,1,1,1,m} + \sum_{i=4}^{7}\sum_{k=2}^{3}\sum_{l=2}^{4}\sum_{m=1}^{10} X_{i,j,k,l,m} \leq 300000$$

s.t. # 136: Minimum demand of the sugar mill in a working day (j = 1).

$$\sum_{i=1}^{3}\sum_{m=1}^{10} X_{i,1,1,1,m} + \sum_{i=4}^{7}\sum_{k=2}^{3}\sum_{l=2}^{4}\sum_{m=1}^{10} X_{i,j,k,l,m} \geq 285000$$

2.2 Restrictions

- Field’s production of cane
- Harvesting capacity by each mean of cutting
- Cane demand of the sugar mill
- Capacity of storing places
- Equality in amount of cane arriving and leaving
- Capacity of transportation

2.3 Objective Function

$$\min C = \sum_{i=1}^{7}\sum_{j=1}^{4}\sum_{k=1}^{3}\sum_{l=1}^{4}\sum_{m=1}^{10} C_{i,j,k,l,m} \cdot Co_i \cdot X_{i,j,k,l,m}$$

Where:

$C_{i,j,k,l,m}$: Economical coefficient of the objective function.

Co_i: Opportunity coefficient. It only depends on the origin or being more exactly, from where cane is cut, therefore, if the origin is a storing place ($i = 1,2,3$) the coefficient will take the value of 1; for the rest of the origins, $Co_i < 1$.

3. Results and discussion

Origin	Variable (X_{ijkl})	@ of sugar cane	Sum in @
Field # 4	X_{7333}	4033,74194	160000
Field # 4	X_{7332}	4182,25142	
Field # 4	X_{7324}	12388,72020	
Field # 4	X_{7322}	6588,44629	
Field # 3	X_{6333}	3900,30640	
Field # 3	X_{6332}	3176,89258	
Field # 3	X_{6323}	5729,64111	
Field # 2	X_{5433}	27334,24880	
Field # 2	X_{5432}	2266,97681	
Field # 2	X_{5424}	13702,76900	
Field # 2	X_{5423}	6199,38710	
Field # 2	X_{5422}	10496,61810	
Field # 1	X_{4233}	6000,00000	
Field # 1	X_{4232}	13335,88680	
Field # 1	X_{4224}	35699,38720	
Field # 1	X_{4223}	4964,72607	
Field # 3	X_{6133}	60256,92290	125000
Field # 3	X_{6132}	37001,53200	
Field # 3	X_{6124}	6243,07703	
Field # 3	X_{6123}	8099,69385	
Field # 3	X_{6122}	13398,77420	
SP # 3	X_{3111}	60000,00000	160000
SP # 2	X_{2111}	40000,00000	
SP # 1	X_{1111}	60000,00000	

4. Conclusions

- Flexible formulation in different senses:
  - Minimisation of cost transportation
  - Maximisation of sugar quality
  - Planning optimal harvesting for a user-defined period

- Succesfull implementation for the proposed example

- It is necessary to develop suitable interfaces for working in field canditions with a such model.

5. Papers derived

Lopez-Milan, E. and Plà-Aragonés L.M. (2014) An Operational Computerised System to Manage the Supply Chain of Sugar Cane. *Annals of Operations Research*. doi: 10.1007/s10479-013-1361-0

López, E., Miquel S., and Pla, L.M., (2006). Sugar cane transportation in Cuba, a case study. *European Journal of Operational Research*. 174: 374-386

Gracias por su atención

Thanks for your attention