Optimal location of receiving repositories in a sugar beet harvesting network

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SUMMARY

Sugar-beet can be transported from the field to the sugarworks in many ways. The transportation can be direct (uniarticulate) that is without takeover or combined (polyarticulate). In case of combined transportation, several transporting vehicle and usually more subbranches of transportation (tractors, vans, railway cars) are co-operating. The second most labour-intensive action of sugar-beet receiving is cleaning. The transport and handling of the contaminants separated during cleaning is quite a difficult task, especially if the cleaning is done inside the sugarworks. The problem can be solved by setting up mobile cleaning units in so-called repositories near to the fields. This study gives answer how to determine the number and the location of the repositories, optimized from the point of view of transportation.

INTRODUCTION

The number of the factories and the needed capacity of the Hungarian beet industry is determined by the EU's production quota, that Hungary won in December 2002. The factories are not interested in producing more or producing less sugar than the amount of the quota, arranged during the connection treaty, because the overflow can only be exported at a very low price outside EU, while producers can lose valuable opportunities on the market if they produce below quota.

It is well-known that sugar-beet production is one of the most paying in field growing, so people who have the right to transport sugar-beet form a very privileged group, hard to get in. The privilege and the earning is derivable from the EU's guaranteed minimal sugar-beet price that will expectably be 11-12 thousand HUF/ton. The interventional price of sugar is 155-170 HUF/kg and the factory price is 180-195 HUF/kg, depending on the market-rate of the Hungarian Forint. These prices let reaching higher profit than now, either in sugar-beet growing and in sugar producing too.

But it would be irresponsible to do nothing and neglect further developments after having the quota. On one hand the EU's reformation of the sugar market is expected to aim the increased defeatment of the differences between countries by competitiveness. This results that the sugar-beet production shifts to the regions that can produce more effectively and the less effective areas will have to decrease or even terminate their production. On the other hand the profit that can be realized from the production is not only depending on the income, but it depends on the costs too, so the aim of the developments or at least a part of them must be about cutting the costs.

This study only investigates a narrow field of the developments, the actions after lifting of the sugar-beet, moreover from the point of view of transportation and transportation costs.

THE CURRENT PRACTICE OF SUGAR-BEET TRANSPORTATION

The collection of sugar-beet from the fields can be direct (uniarticulate) or combined (polyarticulate). According to the experience in the past, the costs of loading, storing, cleaning and transportation from the field to the receiving station were paid by the factory, independent from the type of the transportation.

In case of direct transportation the sugar-beet gets to the factory from the field without take-over, by road-vehicles. This solution can be seen on the left side of Figure 1 (alternative 1.). The receiving station is the factory itself, where the sugar-beet is cleaned and clamped after the qualitative and quantitative acceptance. The advantages of this solution are: adaptability, no need for takeover. But the high amount of contaminants (soil, furrow-weed residues, etc.) that can get inside the factory is a disadvantage, because the storage and removal of these materials increase the costs.

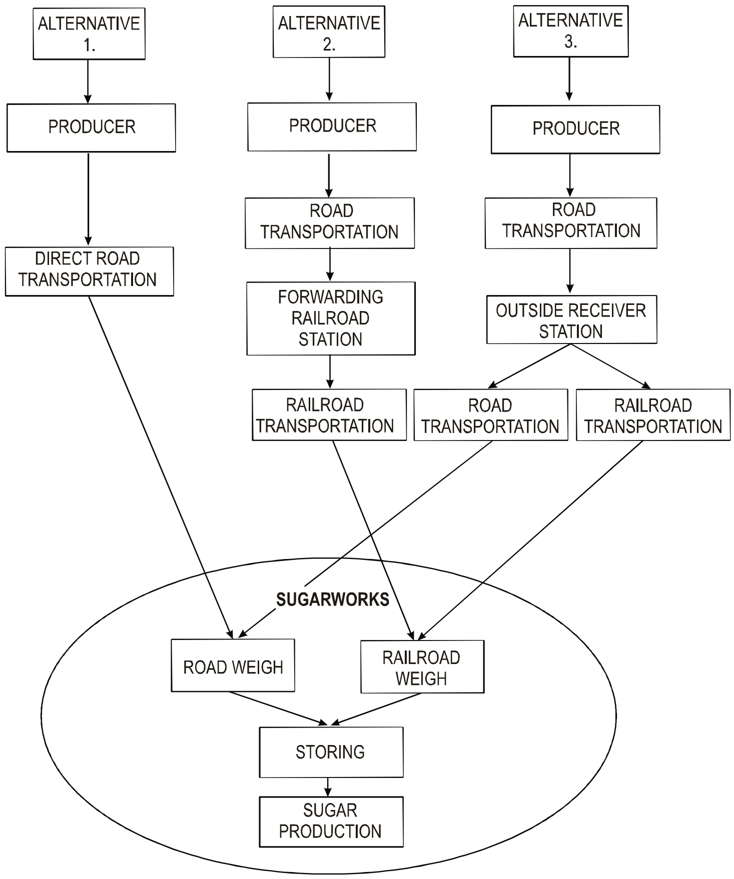

Fig. 1. Former solutions for transporting between fields and sugarworks

One way of the combined transportation is (Fig. 1, alternative 2.) when the farmers take the sugar-beet on road-vehicles to the forwarding railroad-station, from where in the second phase of transportation, the material gets to the factory by railroad. During this process, the sugar-beet is cleaned with mobile or stationary machines, before or after the road transportation. The receiving station here is also the factory. The mechanical cleaning of the sugar-beet that comes on railway is hard to carry out, so they put the material from the carriage right into the factory's cleaning system, from where it goes to production in 12-24 hours. (Wet storage is not allowed, while the autolysis of sugar on the wet surfaces is very strong, because of the raised activity of micro-organisms. Further problem is that the washed dirt means huge load to the factory's sewer.)

The third solution (Fig. 1, alternative 3.) is when producers transport to the outside receiver station on public road. After the qualitative and quantitative acceptance of the sugar-beet, before the temporary storage, the factory owned cleaning and clamping machines, operating at the station do the necessary procedures. The transportation right to the factory can be done on public road or on railroad, depending on the receiver station's traffic connections. This procedure could let the accepted sugar-beet to put it right into production, because of it's cleanness. But the build-up of the public road receiver stations do not let the same, hence the sugar-beet coming from these receiver stations, after the repeated cleaning the sugar-beets often mix with the carriages that come from public road, according to alternative 1. Because of the repeated cleaning, the rate of the broken beets is the highest in these carriages.

LOADING AND TRANSPORTING BY ENHANCED CLEANING

Way of transportations written above, have advantages and disadvantages that we represented without mentioning all of these. However there is a fourth method that is called enhanced cleaning by the profession and that is putting all of the advantages of the above mentioned methods together. The body of it is that they transport the sugar-beets on public roads to the storing repositories, where they are clamped and then a high-performance (150-450 tons/hour), self-propelled, so-called cleaning-loader machines clean and put the raw material to the public road vehicles. The treated sugar-beet transported into the factory can be processed immediately after the qualitative and quantitative acceptance. The advantages of enhanced cleaning: the amount of the contaminants (soil, furrow-weeds, etc.) that can get inside the factory is minimal, so there is need to care about their storage and treatment. The transporting costs decrease, because less weight must be transported into the factory and there is no need to transport the contamination. The floating-water and cleaning-water consumption decreases, that cuts back the costs of water handling and cleaning. The decrease of the contamination in the carriages increases the objectivity sugar-beet grading and it also decreases the margin of errors in measurements. It is an environment-friendly procedure that fits for the more and more strict environmental rules.

Not only the above mentioned advantages motivate the establishing of the method, but the guaranteed, minimal EU price of sugar-beet paid to the farmers that contains the cost of the transportation between the field and the repository, the clamping, the cleaning and the loading. The transportation cost between the repository and the factory would still be paid by the sugarworks. This means that the interest of the sugarworks is to have repositories that are easily accessible, as close to the factory as it is possible. This is a bit different from what the producers want.

It can be easily conceded that the most sensitive point of the establishing is choosing the place, the number and the size of the sugar-beet repositories. When assignating the place of a repository it is a basic term to the warehoused sugar-beets to be easily transported to the factory in case of extreme weather circumstances too and transportation does not endanger the continuous operation.

Setting the optimal place of repositories (that needs the least transporting costs) is currently very difficult, because the lack of agricultural road-network with concrete surface. The only solution to the problem is evolving the concrete surfaced roads between the existing agricultural roads and the optimally set repositories. These costs would fall on to the producers and the sugarworks. (A good example is the Sugarworks in Kaba, where the factory and the farmers jointly invested to built repositories, linked directly to the concrete surfaced road network within an 'Agricultural road and repository building' program.)

Fig. 2. Cleaning and loading machine in operation

The size of a certain clamp is depending on the operating, the capacity of the cleaning-loader machine, the size of the served field and on the danger of freezing. Different cleaning-loaders need different sizes of repositories built. Machines fed with loaders can be used at any size of clamps. Machines that have own pick-up boards need 6-8 m wide clamps (Fig. 2). Small clamps can be built by special transporting vehicles and in favourable cases they can be directly built with the bunkered harvest machines. In case of conventional transporting with trailer a particular loading machine is needed. When using small clamps the danger of freezing is higher that can be avoided with covering.

ASSIGNMENT OF THE OPTIMAL LOCATION OF REPOSITORIES

The assignment of the optimal location of a repository is a so-called multidivisional and two-step depot exploring problem, where the repositories with unknown co-ordinates and the sugarworks with known co-ordinates are the centers, and the sugar-beet fields are the served depots. First step of transportation is between the fields and the repositories, the second step is moving between the repositories and the sugarworks.

In the problem the capacity of the served depots (fields) and the co-ordinates of the field centers are known. Capacity can be calculated from the size of the area and from the yield. The number of repositories equals to the number of cleaning loaders. Although the loaders are movable, it seems to be suitable to use the precept of one loader per repository. The capacity of the repository is defined by the performance (180-220 tons/hour) of the loader. According to the experiences a loader can clean 100 thousand tons of sugar-beet in a season, that means it can serve 1700 hectares of field, based on a 60 tons/hectare yield. Sugarworks are centers with unusual characteristics, because not even their capacities, but their co-ordinates are also known.

The questions that need to be answered are the followings: Where to put the repositories? How to set up areas, that is to which repository to transport from the certain sugar-beet fields?

Based on the above mentioned things, the condition system and the objective function of the mathematical model that can solve the problem is the following:

(1) $X_{ij} \geq 0$, $Y_{ik} \geq 0$, where i=1,2,...,n, j=1,2,...,m, k=1,2,...,l

(2) $\sum_i X_{ij} = t_j$

(3) $\sum_j X_{ij} \leq f_i$

(4) $\sum_i Y_{ik} \leq r_k$

(5) $\sum_j t_j \leq \sum_i f_i$

(6) $\sum_j t_j \leq \sum_k r_k$

(7) $Q = \sum_i \sum_j X_{ij} \sqrt{(x_j - u_i)^2 + (y_j - v_i)^2} + \sum_i \sum_k Y_{ik} \sqrt{(\xi_k - u_i)^2 + (\eta_k - v_i)^2} \rightarrow \min$

Where n is the number of repositories, m is the number of the sugar-beet fields, l is the number of sugarworks, X_{ij} is the amount transported from field j to repository i, Y_{ik} is the amount transported from repository i to factory k, t_j is the capacity of field j (equals to the yield of the field), f_i is the capacity of repository i, r_k is the capacity of repository k, f_i' is the amount transported to repository i, $\mathbf{r}_i(u_i, v_i)$ are the co-ordinates of repository i, $\mathbf{r}_j(x_j, y_j)$ are the co-ordinates of field j, $\mathbf{r}_k(\xi_k, \eta_k)$ are the co-ordinates of sugarworks k, Q is the transportation work.

Table 1

Combinations table

	T_1	T_j	T_m	D_1	D_i	D_n		Bound
D_1	c_{11}	c_{1j}	c_{1m}	M	M	M	$\leq$	f_1
D_i	c_{i1}	c_{ij}	c_{im}	M	M	M	$\leq$	f_i
D_n	c_{n1}	c_{nj}	c_{nm}	M	M	M	$\leq$	f_n
G_1	M	M	M	d_{11}	d_{1i}	d_{1n}	$\leq$	r_1
G_k	M	M	M	d_{k1}	d_{ki}	d_{kn}	$\leq$	r_k
G_l	M	M	M	d_{l1}	d_{li}	d_{ln}	$\leq$	r_l
f_j	t_1	t_j	t_m	f_1'	f_i'	f_n'		
	k_1	k_j	k_m	k_1	k_i	k_n		

The solution of the object is to set up areas from the sugar-beet fields and to find the center points of the certain repositories. This means we lead back the problem to single area problems.

The first step of he solution is to make areas, that means classifying each field to a certain repository. The simplest way to that is to use a so-called combinations table (Table 1.) in which c_{ij} is the distance between repositories (D_i) and sugar-beet fields (T_j), d_{ij} is the distance between repositories (D_i) and factories (G_k) and (t_j) is the capacity of the field, (f_i) the repositories and (r_k) the factories.

The elements of matrix c_{ij} can be counted by:

$$c_{ij} = \sqrt{(x_j - u_i)^2 + (y_j - v_i)^2}\ ,$$

and the elements of matrix d_{ki} can be counted by:

$$d_{ki} = \sqrt{(\xi_k - u_i)^2 + (\eta_k - v_i)^2}\ .$$

For this we take the starting co-ordinates of the repository $\mathbf{r}_i(u_i,v_j)$ discretionarily before the first iteration.

For the making of the areas, similar to the *Vogel-Korda* method, we figure differentials to every column (k_i) that are the differences of the two smallest elements of the column.

First we complete the making of the areas in the D_i–T_j partition, that means first we order the sugar-beet fields to the repositories. We start programming in the column, where the difference is the biggest. We place the biggest amount possible (X_{ij}) onto the smallest element of the column and we continue programming with the column that's difference is the next in the row. We eliminate the rows and columns where there are no more elements left. When eliminating a row, we have to calculate the differences again. We have to take care not to exceed the given upper bounds (f_i).

After ordering the sugar-beet fields and the repositories to each other, we calculate the amounts transported into the repositories by using the formula:

$$\sum_j X_{ij} = f_i'\ , \qquad i=1,2,...,n$$

We fill in the results to the table and we complete the making of areas in the G_k–D_i partition also by using the method described above.

After setting up the areas, each area can be examined as individual, single area problems. This way the places of the centers $\mathbf{r}_i(u_i, v_i)$ can be determined by using the iterative formulas of the center-investigation beside co-ordinates. The iterative formulas of the center-investigation beside co-ordinates in area i are:

$$u_i^{(k+1)} = \frac{\sum_j X_{ij} x_j / c_{ij}^{(k)}}{\sum_j X_{ij} / c_{ij}^{(k)}}\ ,$$

$$v_i^{(k+1)} = \frac{\sum_j X_{ij} y_j / c_{ij}^{(k)}}{\sum_j X_{ij} / c_{ij}^{(k)}}\ ,$$

where $c_{ij}^{(k)} = \sqrt{(x_j - u_i^{(k)})^2 + (y_j - v_i^{(k)})^2}$, and k is the number of iterations.

After every iterative step we investigate the following conditions:

$$\left| u_i^{(k+1)} - u_i^{(k)} \right| \leq \varepsilon ,$$

$$\left| v_i^{(k+1)} - v_i^{(k)} \right| \leq \varepsilon$$

Where ε is an arbitrarily small number. We finish the iterative process if the conditions are fulfilled, otherwise we go on working with the method.

We make a new combinational table from the new center co-ordinates ($\mathbf{r}_i(u_i, v_i)$) and we put the sugar-beet fields again into new areas. The method finishes when two combinational tables lead to the same areas, two times over. Note that the success of the method is highly depending on the determination of the starting values. It can happen that we only get local position of minimum. We can avoid this by calculating several times with different starting values. We can only be satisfied if we get the same results with different center series.

The final results tell us the co-ordinates ($\mathbf{r}_i(u_i, v_i)$) that mark the optimal places of the repositories (D_i), the effective capacity of the repositories (f_i'), the sugar-beet fields (T_j) belonging to the repository i and the repositories that belong to the sugarwork k.

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