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Optimization and process development methods in the production of sugar from Cuban sugar cane

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Abstract: Cuba's economy has fluctuated strongly due to COVID-19 and natural disasters. In addition, sugar production, which is Cuba's main export product, also fell sharply. In the absence of underdeveloped industrial technologies and digitization, Cuba currently has to allocate its resources with even greater consideration. That's why utilization and optimization of sugar production and transport can take advantage of its inherent potential and reserves. After presenting the history of sugar production and its current, mainly local, technology, we present three simple methods, which do not require very professional knowledge nor expensive software or hardware to optimise these processes. We recommend the establishment of basic collection points, which would operate as specific logistics centres, with the role of service provision and pre-production in addition to the collection. Also, the paper proposes a method that can be used to design layouts in 3D, making the current sugar production process more compact and efficient.

1 Introduction and literature research

Refined sugar plays a significant role in providing food for the growing world population. Compared to its weight, it has a significant energy content. Also, in the right hands, it is easy and sustainable to produce, and although excessive sugar consumption is considered unhealthy, it is part of our daily diet. Refined sugar can be produced from a variety of plants [1], but there are two proven sources in industrial quantities, which are ideal due to their high sucrose content: sugar beet (15-20%) and sugarcane (13-15%). In the continental climate of Europe, as well as in Hungary, sugar beet is the primary source of sugar, as it is the best source of sugar in our climate zone without any special maintenance. In subtropical environments, such as the one in which the Republic of Cuba belongs, the cultivation of sugar cane is more beneficial. In order to understand the sugar industry in the Caribbean region, we need to go a little deeper: where it comes from, what it went through and how it is currently. There are many sources available for this in the online literature databases. It is enough to enter the keywords "Cuban sugar industry", and more than 57,000 results are found in Google Scholar or 11,300 in the Elsevier database. One of the most significant works is the 1991 "The economics of Cuban sugar" by J Pérez-López [2], in which he describes the sugar production and trade activities in Cuba from the 1820s to 1988. He presents the plan-based sugar increase and their challenges in a little more detail in "The performance of the Cuban sugar industry 1981-1985" [3] or during the "Great Depression" [4] also in the 1970s [5]. The previous works did not write about the beginnings of sugar-making by slaves [6,7]. A large number of studies [8] and discussions [9] about the issues of the Cuban sugar industry have begun in the last 30 years. These three documents describe the recent restructuring of the sugar industry in 2002 [10] and its collapse in 2004 [11] and 10 years later [12]. As can be seen from most documents, the Cuban sugar industry is in decline, even though sugar is not only part of the Cuban diet [13], but a proven and important export item that is increasingly needed.

After the historical review, we focused on industrial applications and technical solutions from sugarcane cultivation through transportation to processing and delivery to customer, which helps us explore the problems and already proposed solutions for the entire system. The book "Cuban sugar industry: Transnational networks and engineering migrants in mid-nineteenth century Cuba" [14] provides a comprehensive picture of the technological and transportation solutions of the sugar industry in the middle of the 20th century. At this time, sugar was harvested primarily by hand or with very rudimentary machinery, transported by animal power and carts, furthermore, processed in various mills that used a lot of hand power and steam engines. The real development came in the 1950s, when machines, tractors and trucks were delivered to Cuba from the USSR and the Eastern European block. Although the harvesting tools were not suitable (they were designed for sugar beets), they greatly boosted productivity. The railway to Cuba was one of the first to be built in the middle of the 19th century. By the middle of the 20th century, it completely covered the island, which was very important for the inland areas and productivity, but its development stopped after the 1960s [15]. These infrastructures and techniques exist to this day, unfortunately seeing very little development since then [16]. Unfortunately, many problems arise from the ageing infrastructure, technological machines and means of transport, which in themselves are significant, but in aggregate, represent a serious cost to the producers. One solution would be the automation of the industry [17], which, although the initial cost is high, would be very worthwhile in the long run. Also, the replacement of the old machinery fleet, which is already being investigated, for example, with new harvesting machines [18,19], can be a huge improvement and have long-lasting benefits.

However, there are opportunities for development within research and studies from several angles. In addition to the increasing fossil energy prices, several studies have been prepared on the energetic utilization of sugarcane as biofuel for vehicles [20] or also as bioethanol for direct combustion in power plants [21,22]. The alcohol industry is also a large receiving market, where new technologies appear both in the chemical effects of alcohols [23] and in the forms of distillation [24]. Sugar and its by-products are used all over the world and are in high demand [25]. Some of them can be used in the mill (for heating) or in the fields (as a soil conditioner and fertilizer). The rest (paper, chemical, alcohol and yeast industries and animal husbandry) must be stored, transported and sold [26].

There are those who see the growth in the control and optimization advantages provided by programming, such as controlling a multi-injection furnace with a fuzzy principle [27]. Simulation effectiveness studies have also been carried out in the sugar industry [28], and there are those who see the future in the effectiveness of a fully autonomous harvesting machines [29]. Unfortunately, Cuba is still lagging behind most countries in terms of IT innovations, digitization and access to the Internet [30], but it is constantly developing and is playing a major role in universities [31].

From the previous findings, it can be roughly deduced what the precarious situation is like from a logistical point of view in the field of the Cuban sugar industry. Unfortunately, the situation is not very promising, but there are those who see this as a great opportunity for development. Cuban industry must also reach the level of being an active part of global supply chains [32]. This was confirmed by several people not only with principles, but also with cost and productivity calculations [33] using Excel, solving scheduling problems [34] and studies [35]. In terms of infrastructure, the ports are in good condition and suitable for connecting to the supply chain [36]. In addition, the food distribution chain within Cuba was examined, in which sugar also plays a major role.

A life cycle analysis [37] was also created of the sugar industry, the produced sugar and its by-products, which evaluates the products and by-products from extraction to final usage and examines its environmental effects. The study establishes that the methods and machinery need to improve. An example of this is the new use of sugar industry waste [38]. Based on our literature research, it turned out that there are countless people studies the sugar industry and its history. However, we found very few, about 10 publications from the technological and logistical side, most of which were mentioned in this chapter. Of these, only 4 deal with the topic of logistics optimization, and within them, the emphasis is more on the optimization of transport in the existing system with the existing tools and infrastructure. In the following, we present methods that can be used to improve both external and internal logistics processes. But to understand the development potential, we first need to know the system we want to improve.

2 Process and products of sugar production

In order to reveal the problems and under-developed areas in the sugar industry, we also need to understand the process of sugar refinement. The Hungarian sugar industry is a very good example of this, as the process of sugar refinement is almost everywhere have the same process. Until the 2000s, Hungary was one of the main sugar producers in Europe, with 133 sugar factories operating in its territory since 1830 [39]. Unfortunately, since 2008, only 1 sugar factory in Kaposvár has been allowed to operate, the reason for which is the "sugar reform" signed upon joining the European Union [40]. This shows that Hungary's roots in sugar production go back quite a long time. The process shown in Figure 1 is also a modified diagram of the Hatvan sugar factory, and the technological steps described after it is also derived from it.

The subtropical environment of the Republic of Cuba in the Caribbean provides an ideal opportunity to produce sugar from sugar cane. Sugar cane is grown on large inland lands where the amount of precipitation is at least 60 cm per year. Then, it can produce up to 10-15 kg/m2 of sugar cane. Natural rainfall must be supplemented with irrigation, as it does not tolerate long droughts and cold wells. For these reasons, sugarcane can be grown for 6-7 months a year, which in turn means multiple harvests. The sugar cane does not need to be replanted every year. Instead of the cut stalks, a new shoot starts every year from the remaining stalks and root system, which greatly facilitates the cultivation. Due to the large monoculture and large fields fertilization is still necessary. 9% of potassium-based fertilizers are used for sugarcane cultivation every year [41].

The production of sugar is similar for both plants, after the formation of molasses it is completely the same.

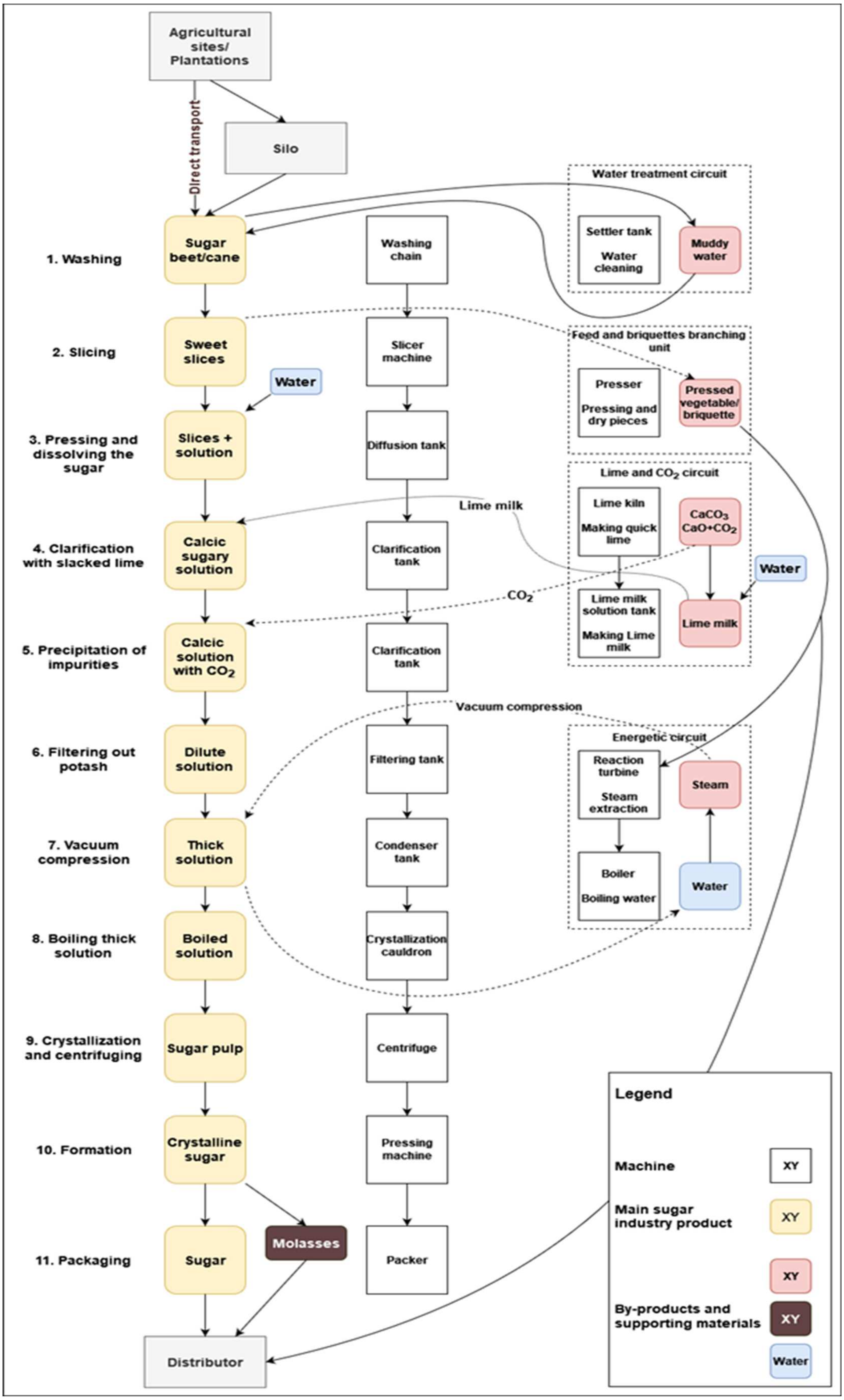

Figure 1 The sequence of sugar production in the Hatvan Sugar Factory

2.1 Technological steps of sugar refinement:

1. **Washing**: After harvesting and storing/transporting the beet/cane the very first operation is the washing process. The incoming beets/reeds move in bulk, and the washing begins as soon as they are unloaded from the wagons/silos/trucks with a high-pressure water jets. In the water stream addition to the plant there are also earth, stone, wood and other pollution must be captured. The washing operation is complex with multiple machines and filters. On the washing chain, the plant + water mixture is first carried forward by the gravity slope and then by water moved by a high-pressure compressor. At the end of washing, the flowing water is separated from the plant. The beet is taken to the slicer by a conveyor belt, and the wastewater is cleaned and then returned to the washing water cycle.
2. **Slicing**: The operation (called shaving for beets, splitting for canes) is basically the same as slicing vegetables at home. In the sugar factory, this operation takes place on a machine designed for large quantities and continuous operation. The slicing knives are attached to a disk located at the bottom of a cylinder. The descending disc rotates at high speed and slices the plants. The vegetables fed from above and pushes those located below into the rotating cylinder with rows of knives with its weight. The sliced parts fall onto a conveyor belt with a rubber belt or multi-segment belt, which transports the slices to the next location.
3. **Pressing and releasing the sugar**: The beet/cane enters a second water circuit. After the outer water circuit of the washing, this is the internal sugar factory water circuit. In this water circuit, the vegetable slices are first soaked in warm water so that the sugar goes into solution through the cell wall (diffusion). The place of action is the diffusion tank. The beet/cane slices leaving the process are first pressed, because the loosely structured material still contains a lot of sugar solution. In the case of beets, the pressed material is valuable feed, which is constantly transported, and in the case of sugar cane, feed, manure, and wax are produced from it, and then the remaining dry part is used to heat certain processes of sugar production.
4. **Clarificatio**n: The impurities in the sugar solution are precipitated, clarified (with lime milk) and fixed (with carbon dioxide). These operations are also carried out in large tanks. The lime milk is added to the solution in the first step of clarification. $Ca(OH)_2$ reacts with impurities. Even in the case of sugar cane, they use mainly lime milk for the clarification process, however, to extract the harder-to-access sugar even faster and more effectively, phosphoric acid is also added to the sugar solution.
5. **Precipitation of impurities:** Carbon dioxide (CO_2) is added to the solution. The carbon dioxide introduced into the solution reacts with the calcium hydroxide ($Ca(OH)_2$) and the impurities are precipitated into calcium carbonate ($CaCO_3$). The resulting precipitate can then be separated by filtration. Both lime and carbon dioxide are produced by heating limestone (traditional lime burning) in a separate factory: the lime incinerator, usually belonging to the sugar factory.
6. **Filtering out the lime sludge:** The lime sludge produced during clarification is filtered out of the solution. This operation is carried out on a filter press. By filtering out the impurities, a sugary water solution called dilute is created.
7. **Vacuum compression:** The slurry is heated with steam (carried by pipeline from the power plant connected to the sugar factory). When the hot solution enters a low-pressure space, it effectively evaporates part of its water content. The end product of the operation is the thick juice.
8. **Boiling thick juice:** Boiling takes place in huge containers. This operation involves additional water loss, and at the end of the process, the sugar solution becomes saturated and suitable for crystallization.
9. **Crystallization and centrifugation:** The crystals in the thick, saturated sugar solution are centrifuged. The centrifuge here is a rotating steel cylinder with a perforated surface. When the thick sugar paste is placed in the centrifuge, it partially cools, and the liquid part exits the perforated surface and the sugary solution is further thickened. Granules of sugar floating on the surface fall below, where they are caught in huge pans. The solution remaining at the end of repeated thickening (about three times) is molasses, which is also used in confectionary preparations (in the past), in fodder and in the preparation of syrups.
10. **Shaping:** The small crystalline material created is molded into the shape characteristic of the products. It used to be used in Hungary to sugar loaf. Today, it is mostly crushed into sugar cubes or refined into powdered sugar. However, most of the production remains in the form of granulated sugar. If we want to get brown sugar, we can achieve it by incompletely separating the molasses (impurity) or by adding it afterwards.
11. **Packaging the final products:** Granulated sugar households is placed in 0.5/1/2 kg mostly paper packaging or 15/25/50 kg paper-based bags or 1 ton big bags. Sugar cubes come in half-kilo or one-kilo boxes [39].

2.2 Main and by-products of the sugar industry

The main and by-products of the sugar industry have already been mentioned in the literature research, but the complete list and areas are shown in Figure 2. It shows us that nearly 40 different products can be produced by processing sugarcane, of which energy production plays a prominent role, which can be used for heating the furnaces and reactors in the sugar processing plant or release for sale. Fibers play a huge role in the paper industry, as cellulose or paper raw material, or as in the food industry as Xylitol (sugar substitute). In addition, it places major role in the plastics- and construction industry, not to mention being used as litter or as a base in mushroom production. Many things can also be made from molasses. It is used in the alcohol industry: rum and other spirits are mainly produced for consumption, as disinfectants and ethanol. It can also be used to make feed for animals and fertilizer. When fermented, vinegar, acetic acid, citric acid, glycerol, lactic acid or yeast can be produced from it or with it. It also plays a major role in the chemical industry as a component of organic substances [25].

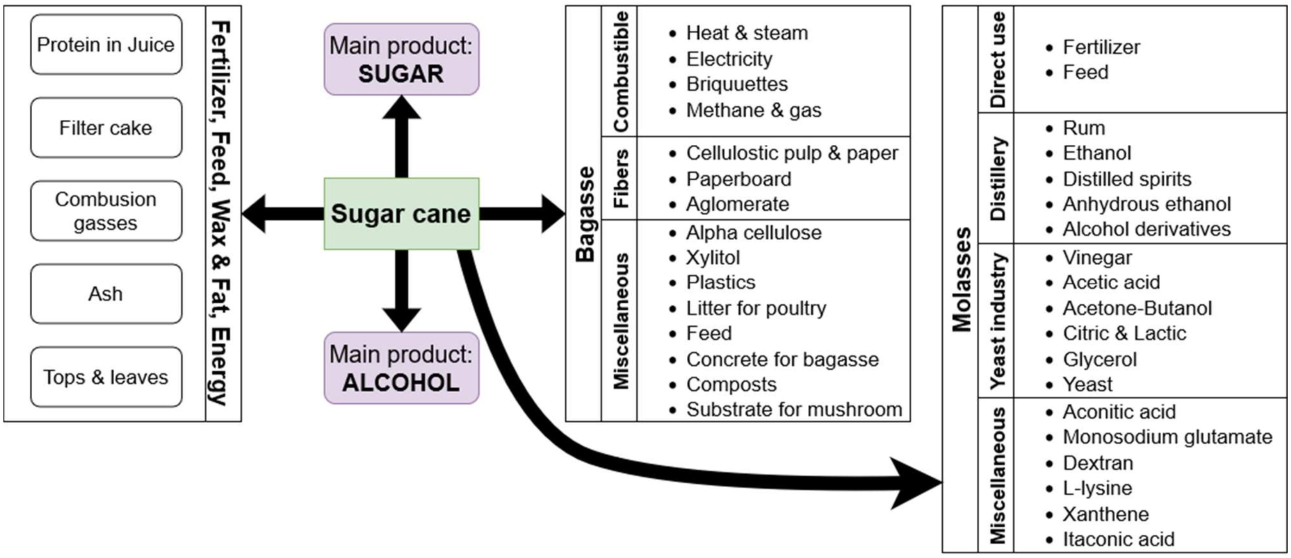

Figure 2 Sugarcane and sugar industry products and byproducts [25]

Now that we have become familiar with the processes, technology, infrastructure and production tools that are available or that are proposed by other researchers, we can see the system as a whole and make recommendations for it.

3 Optimization methods in logistics

One of the most obvious long-term cost reduction methods is to replace outdated tools and machines with newer, more modern and more effective tools. This is also true for the technology equipment that is in the sugar refinery, as well as for the means of harvesting and transportation. A truck made in the 1950s-1970s can consume 2-3 times more fuel than one made after 2000, not to mention the better working conditions and comfort in the newer vehicle. This is also true for hand-powered machines, tractors, harvesters, and for railway vehicles. Although this is a large investment and maintenance is also more difficult for newer machines, the payback time is expected between 5 and 10 years [19].

3.1 Location of one or more collection points from an area-based source

From a logistical point of view, a more serious task is the number of collection points to be established in a production area and the planning of transport routes and schedules for the harvested sugar cane to reach the sugar refinery. This can be seen through a specific example in the publication [33], in which they investigated the location of the collection points where the harvesting equipment collects the cut sugarcane and places it on the truck on several plantations in a larger production area. From now on, these collection points can be considered fix points since the area and yield rate of the lands will not change significantly in the future. As a proof of this, the authors created an algorithm written in Excel, which can calculate the ideal location of these points with various parameters, which also take into account the costs of transportation and collection, thus achieving an 8% fuel saving. A similar study was carried out by researchers in Iowa (USA), where they collect methods for gathering and transport challenges of local farming, including but not limited to the sugar industry [43]. In logistics, these are called the Center search or Multicenter search (defining and grouping of several locations) problem, in which the transportation work and transportation costs are usually the most significant components, but local features such as labor-, rental-, construction-, and infrastructure costs can also be taken into account. In the method of center search, the selection of the optimal location can be determined with iteration steps and ever-increasing resolution, however, in the case of multi-center search, clustering (group formation) is also involved, so this is a much more difficult task (NP-Hard) and there are no exact method for it. Usually, the location of several collection points is determined using heuristic methods and simulation [44].

3.2 Multi-stage collection and pre-processing method

The next cost reduction method is based on similar principles as the previous one, but it handles the problem one level higher. Instead of small local sugar processors, of which there are relatively many in Cuba, only the larger ones would operate; they are more efficient anyway; and the smaller ones would only carry out the first three steps. These would be the pre-processing plants, that collects, chops, and presses the received sugar cane. The press squeezes out the sugary juice and deliver it to the refineries in tankers (trucks/wagons). The process of this can be seen in Figure 3. Systems operating on a similar principle already exist in other areas [45]. In this case, a lot of idle traffic can be eliminated or reduced, since the vehicles full of sugar cane only have to travel part of the length. Squeezed and condensed juice requires much less space and mass than fresh sugar cane, but a vehicle with tanks is required to transport it. The less space and weight significantly reduce the transport work and cost, if a railway line is built between the pre-processing plant and refinery, the transport cost can be reduced to tenth up to twentieth of the original (truck) one. In addition, the pressed biomass, which rich in fiber, remains in the place where it is used for energy (burning) or fertilizing the crop fields. For other uses the pressed pulp also needs to be transported, but in a more compact way. Burning is necessary anyway to thicken the thin sugar-rich juice. The pre-processing plant would also be good, as it would reduce the amount of machines, which would give more attention to equipment where maintaining cost can be reduced and more effective ones could be bought from the same budget.

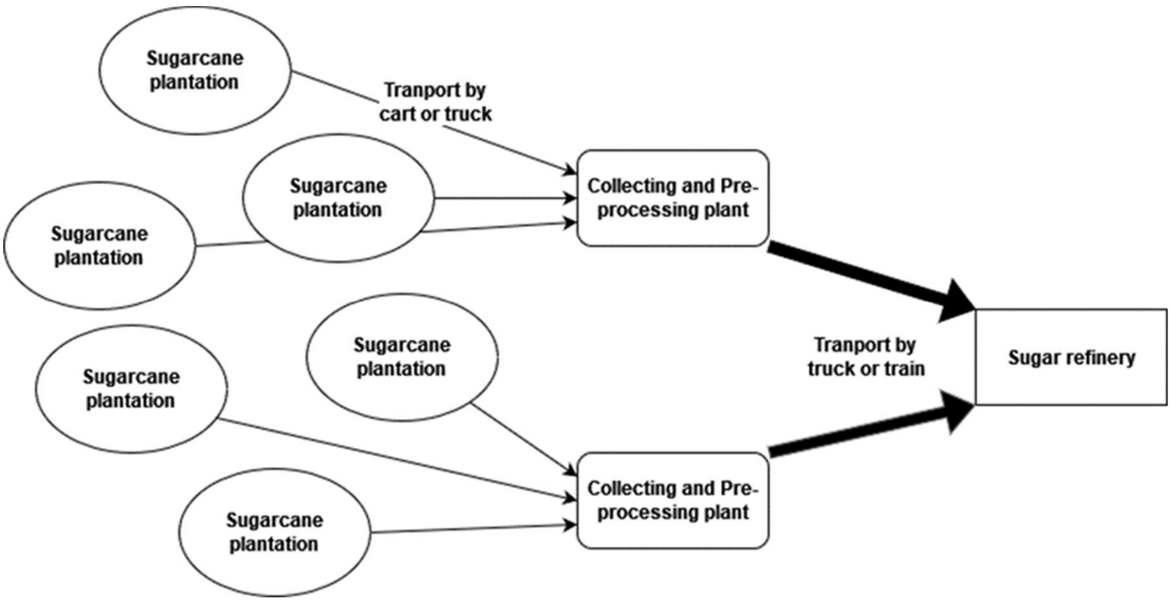

Figure 3 Multi-stage collection and pre-processing

3.3 Multi-stage collection and preprocessing method

Although the process, technology and machines of sugar refining are constantly developing, there are no major changes or variations in the process. The entire process forms a large chain, where sugar cane/beet enters the system from one direction and two important products (sugar and molasses) come out at the end of the process. For this, of course, other generally liquid or gaseous substances must be added; mainly water, lime milk and CO_2; but the process, as shown in Figure 1, is very linear. In the case of sugar processing, most technology equipment is tank-like in which various physical or chemical modifications take place. These machines and systems are large, require a lot of energy and move large quantities. In order to primarily save energy (transportation and thermal energy), the basic principles of logistics must be taken into account when designing the refinery. Often, these machines and the entire system are located at ground level, typically arranged in a line or U-shape, which means easy access and less stress on the foundation. The layout at ground level is only permissible from the point of view of rental or purchase costs if the area on which we are building is considered cheap on an area basis, if this is not true, the upward expansion must be considered. Easy access at ground level also has the advantage for maintenance and cleaning, however, if this is not usually a problem and can be solved in another way, then the multi-level arrangement is preferable. In the case of a multi-level arrangement, the placement of machinery and technology equipment is more expensive, as a supporting structure must be created for it, and maintenance is considered more difficult due to the more compact arrangement and the work must be performed high up. However, multi-level facilities have a big advantage compared to ground-level ones, which is also true for liquids and bulk solids: once

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the material has been lifted, it can move with the help of gravity without much energy input. This one-time, larger lift is generally much smaller than multiple smaller lifts and requires fewer machines, usually pumps. In addition, the outlet of the machinery and the inlet opening of the next equipment can be placed closer to each other, which is associated with the shortening of the transport routes, which in this respect results in less investment and less maintenance.

Unfortunately, there are not many well-developed methods in the literature for arranging the equipment of multi-level production, most people only listen to their inner intuition even at ground level. There are other heuristic methods, that uses heuristic algorithms, such as Genetic Algorithm for single floor layout design [46]. One of the most used single-level methods is the CORELAP (Computerized Relationship Layout Planning) method, which is an improved version of the MUTHER method [47,48]. Once the relationships between the various objects (machines, technology equipment, locations, etc.) have been determined using the MUTHER method, the relationship matrix is created from it, which is characterized (numbered) either by specific values (amount of material movement, work) or importance indicators. Based on the previous findings the connections between objects needs to be classified into 6 groups [49-51]:

- A: absolutely necessary connection; weight number: 4.
- E: especially important relationship; weight number: 3.
- I: important relationship; weight number: 2.
- O: okay (general) relationship; weight number: 1.
- U: unimportant (no connection required); weight number: 0.
- X: undesirable (contact must be avoided); weight number: -1.

We do this in the same way with the Multilevel CORELAP method, if we do not have specific numbers to describe the relationships.

The main steps of the Multilevel CORELAP method are as follows:

1. **Gathering the necessary initial data:**
   - defining the connection matrix of the objects to be installed, a clustered quadratic material matrix must be created [52]
   - the size of the available area,
   - the approximate area requirements of the objects to be arranged,
   - determination of the raster size (based on area or volume), which must be taken so that the smallest object is at least twice the raster size, but should not be fragmented too much, as the calculation demand increases.

2. **Ranking of objects:**

Following the CORELAP methodology, we add the weights (or other data) of the indicators in the relationship matrix for each object, the obtained values are presented, and the largest one is selected. It gets the highest rank of 1. As a next step, we add the relationship matrix with the weights again, but remove the already ranked object(s) from the calculation. The object with the highest value will be ranked 2nd, then 3rd, and so on. This process is repeated until all objects have a rank.

3. **Construction taking into account ranking and direction:**

Based on the received ranking and raster/volume requirement, we start placing our objects on a grid. The first rank should be in the middle of the middle level and we try to distribute the rasters so that most of them stay on the middle level, but if there are too many, we can flow over to the level above or below it. If possible, try to give regular shapes and do not fragment the objects if possible. As soon as the first one is taken down, the next rank can come, right next to it with all its rasters, if possible at the same level. After that, you can unpack all the rasters in a counterclockwise direction until the first rank has been circled around. After that, it is worth using the middle of the level below and above the first rank, then the main diagonals in the plane, then the main diagonals in space. Figure 4 helps to understand the directions in which 1 is the first-ranked place and then the other rasters should be placed in those directions in ascending order.

The description is not exact, it only gives guidelines as to where you should start when designing a layout. It is recommended to experiment with different raster group shapes and then check with the TCR value.

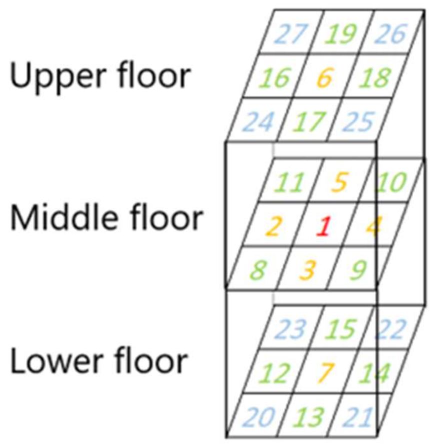

Figure 4 Direction of rastering in multilevel design

4. **Determination of TCR value, evaluation of floor plans**

The TCR (Total Closeness Rating) value shows how close the objects are to each other in the prepared layout, which is obtained by adding the weights of all the objects adjacent to the object as seen from the relationship matrix. If an object is not directly related (they do not have a common side anywhere), then that object is not counted. The higher this number, the better the layout performs.

In the following example, we would like to demonstrate the operation and effectiveness of the method. The areas, connections and approximated material handling values came from a real-life sugar factory in Kaba (Hungary), which represents a sub-modern sugar factory which you can also see in Cuba. The connections (A…X) the type and power of connection and also takes into account the material flow in those connections. These connections are mostly approximations based on the opinions of experts.

Consider a system of 8 machines that we want to deploy. We know the floor space requirements of the machines and we have received how many grids they can occupy. Machines 2, 3, 5 and 6 can also be placed vertically, they do not have to be on the same level. The connection matrix, with the MUTHER methodical ranking, can be seen in the first segment of Table 1 (Machine-Machine grids). The Quantity of types counts how many connections has a machine with the same category of MUTHER classification. The total score calculated by multiplying each category's quantity with it's weights, which are shown in brackets. Based on this the first rank was given to the 5th machine based on the results.

Table 1 Rank 1 of Multilevel CORALAP example task

I.		Machine								Quantity of types (score)						Total score	Ranking	Raster/ Volume
		1	2	3	4	5	6	7	8	A(4)	E(3)	I(2)	O(1)	U(0)	X(-1)			
M	1		I	I	U	O	U	O	U	0	0	2	2	3	0	6		3
a	2	I		O	U	O	U	U	O	0	0	1	3	3	0	5		5
c	3	I	O		U	I	O	O	E	0	1	2	3	1	0	10		6
h	4	U	U	U		O	O	O	X	0	0	0	3	3	1	2		12
i	5	O	O	I	O		A	A	O	2	0	1	4	0	0	14	1	7
n	6	U	U	O	O	A		I	O	1	0	1	2	2	0	8		8
e	7	O	U	O	O	A	I		I	1	0	2	3	1	0	11		4
	8	U	O	E	X	O	O	I		0	1	1	3	1	1	7		7

Based on the description we did the ranking procedure and obtained the following ranking, which is visible in the Ranking column:

Table 2 Ranking of objects in Multilevel CORALAP example task

VI.		Machine								Quantity of types (score)						Total score	Ranking	Raster/ Volume
		[illegible]	[illegible]	[illegible]	4	[illegible]	[illegible]	[illegible]	8	A(4)	E(3)	I(2)	O(1)	U(0)	X(-1)			
M	1		[illegible]	[illegible]	U	[illegible]	[illegible]	[illegible]	U	0	0	0	0	2	0	0	6	3
a	2	[illegible]		[illegible]	U	[illegible]	[illegible]	[illegible]	O	0	0	0	1	1	0	1	4	5
c	3	[illegible]	[illegible]		U	[illegible]	[illegible]	[illegible]	E	0	1	0	0	1	0	3	2	6
h	4	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	X	0	0	0	0	0	1	-1	7	12
i	5	[illegible]	[illegible]	[illegible]	O		[illegible]	[illegible]	O	0	0	0	2	0	0	2	1	7
n	6	[illegible]	[illegible]	[illegible]	O	[illegible]		[illegible]	O	0	0	0	2	0	0	2	5	8
e	7	[illegible]	[illegible]	[illegible]	O	[illegible]	[illegible]		I	0	0	1	1	0	0	3	3	4
	8	[illegible]	[illegible]	[illegible]	X	[illegible]	[illegible]	[illegible]		0	0	0	0	0	1	-1	8	7

Next is the creation of the floor plan by rastering based on the description. We first made it one-story, as shown in the original method, which only came out so compact after several attempts and redrawings. Figure 5. also shows that the neighborhood value of the TCR is 32, where we leave out non-neighboring connections from the connection matrix. This value should be compared with another layout in order to get an idea of its effectiveness, however, the most significant categories A and E have all been preserved in the connection matrix, which indicates a very good layout.

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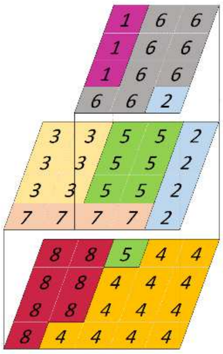
TCR		Machine								Quantity of types (score)						TCR
		1	2	3	4	5	6	7	8	A(4)	E(3)	I(2)	O(1)	U(0)	X(-1)	
	1				U	O	U			0	0	0	1	2	0	1
M	2					O	U	U		0	0	0	1	2	0	1
a	3				U	I		O	E	0	1	1	1	1	0	6
c	4	U		U					X	0	0	0	0	2	1	-1
h	5	O	O	I			A	A		2	0	1	2	0	0	12
i	6	U	U			A				1	0	0	0	2	0	4
n	7		U	O		A			I	1	0	0	1	1	0	5
e	8			E	X			I		0	1	1	0	0	1	4
														Total TCR:		32

Figure 5 Single floor layout and outcome

Lastly, we also made the multi-level version. We solved the problem on 3 levels. Its appearance and calculation can be seen in the following figure.



TCR		Machine								Quantity of types (score)						TCR
		1	2	3	4	5	6	7	8	A(4)	E(3)	I(2)	O(1)	U(0)	X(-1)	
	1					O	U			0	0	0	1	1	0	1
M	2				U	O	U	U		0	0	0	1	3	0	1
a	3					I		O	E	0	1	1	1		0	6
c	4		U			O		O	X	0	0	0	2	1	1	1
h	5	O	O	I	O		A	A	O	2	0	1	4	0	0	14
i	6	U	U			A		I		1	1	0	0	2	0	7
n	7		U	O	O	A	I		I	1	0	2	2	1	0	10
e	8			E	X	O		I		0	1	1	1	0	1	5
														Total TCR:		45

Figure 6 Multi floor layout and outcome

Due to the multi-level arrangement, this layout can have more neighbors than a single level, so the TCR in most times became bigger then in a single layout. In this case the TCR score was 45 and most important elements and connections were also preserved. The theoretical maximum of TCR score in this task is 65, if you add all weights except then negative ones, but this score most certainly can't be reached, due to the massive networking arrangement.

As we have already written, the process of sugar production is not as complex as the connection matrix of the system created as an example, it is much more linear, so simplifications can be applied. The vegetable to be processed must be placed on the highest level and the subsequent technological steps, such as shaping and packaging, on the lowest level. the intermediate steps with machines and fluid tanks can be given as dimensions or rasters to the method. With these facilitation we can easily achieve close to optimal results especially with the help of a computer program.

4 Results and discussion

As the literature research revealed, many people deal with the Cuban sugar industry, but most of these works are more historical, political, and statistical in nature. Very few works deal with the problems of sugar production and try to solve them with either a theoretical or an engineering approach. Our team in the field of logistics would like to transfer and implement this knowledge to the sugar industry environment, and for this purpose it has set itself the goal of familiarizing existing and new methods. In the work, we presented the cost-cutting methods and optimization procedures suggested by others, a multistage model for lowering transport cost, and a layout planning algorithm called Multilevel CORELAP method. Because the Algorithm is a new method, we provided an example for easier understanding.

5 Conclusions

The Cuban economy and sugar industry have recently been hit by major disasters. We cannot alleviate them, but we can change the processes, which are currently very wasteful of energy and resources. In the research, we recommend three main methods for optimizing the Cuban sugar industry and for better realize its inherent potential:

(1) Use the multistage model for lowering transport and storage costs. There should be local or regional logistic centres, with the primary purpose to handle sugar products and materials.

(2) Use these logistic centres near the sugarcane fields to decrease transport cost by lowering the heavy direct

transports length and pre-process the canes to lower their volume and mass for even lower transport needs.
(3) Use the layout planning algorithm called Multilevel CORELAP method, that can help to create better optimized factories, not just for the sugar industry.

With these models and other suggestion both external and internal logistics can be more efficiently for a sugar industry company, not just in Cuba.

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