Crushing method selection for non-centrifugal sugar production by FAHP–ELECTRE I

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Abstract

The non-centrifugal sugar (NCS) industry is one of the oldest small-scale cottage industry in India, whose technological features are not changed for several decades due to which the production and consumption of NCS has reduced significantly. One way to attend this problem is to select the best and sustainable methods among the existing technologies at various stages in the production process. In the production of NCS, juice extraction is the primary and essential process. The present work gives an insight to a logical procedure for selecting a suitable and sustainable juice extraction method for improving the NCS production using multi-criteria evaluation (MCE) technique. The selection process is based on 11 evaluation criteria covering various sustainable factors viz. technological, economic and environmental factors. Fuzzy analytical hierarchical process (FAHP) integrated with elimination et choix traduisant la realité method is the MCE technique considered for selecting the most appropriate crushing method among five alternatives. The results indicated that the power-operated single horizontal crusher is the most suitable and sustainable crushing method for improving the production rate of NCS. The same technique can be used for the other process unit of the NCS production to improve the productivity and sustainability of NCS.

Keywords: non-centrifugal sugar (NCS); juice extraction; multi-criteria evaluation (MCE) techniques

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1. INTRODUCTION

Non-centrifugal sugar (NCS), also known as jaggery, is the traditional Indian sweetener and is being produced in India for the past several decades. It contains 65%–85% sucrose, 10%–15% reducing sugar, 3%–10% moisture and the remaining are insoluble matter such as fat, proteins, minerals, iron and phosphorus [1]. Ayurveda (the traditional Indian system of medicine) prescribes that regular consumption of NCS purifies the blood, prevents disorders of the bile, constipation, respiratory problems, joint pain and anaemia, enhances the production of digestive enzymes, body metabolism and immunity, eases menstrual cramps helps in weight loss [2], etc. Despite being a natural sweetener with good amount of iron, minerals, vitamins along with various health advantages, its production and consumption has reduced significantly from 8.52 to 4.47 MT during the past few decades [3]. One of the major reasons for this decline could be the lack of technological improvements and also not using the appropriate existing technologies for improving the production volumes. The production process of NCS has not changed much in the past several decades [4].

The conventional manufacturing process of NCS (Figure 1) involves a number of processes viz. juice extraction, juice filteration, evaporation and concentration of juice followed by moulding, packing and storing. A typical conventional NCS production unit consists of a crusher to extract juice from sugarcane, an underground furnace equipped with single or multi-pan units for evaporation and concentration of juice to produce NCS [5]. As an attempt towards improving the existing production processses by finding the appropriate technologies among the existing technologies, this paper focuses on the primary and important process of the NCS production viz. juice extraction process.

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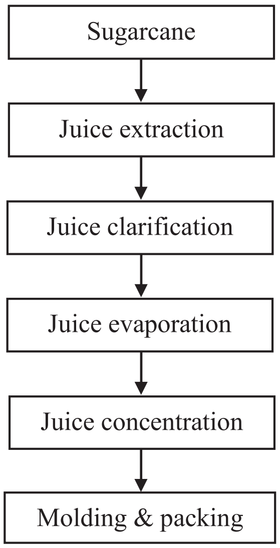

Figure 1. *The conventional NCS production process.*

The main objective of this juice exraction process is to obtain the maximum amount of juice present in sugarcane. At the same time, the crushing method used should satisfy several criteria related to techno-economic and other aspects of sustainability. All this obviously depends on the type of crushing method adopted. Generally, vertical/horizontal three-roller crushers (that use diesel engine or electrical motor as prime mover) and multiple three-roller crushers arranged in series are some of the crushing methods being used in the conventional NCS production [6]. On the other hand, 'multiple mills in series along with shredder and hot water treatment' is the crushing method that is widely used in the sugar industry [7], which may be adopted for the NCS production. Of all these crushing methods that may be considered, not all will be satisfying all the sustainability criteria. Given that multi-criteria evaluation (MCE; also known as multi-criteria decision making) is a branch of operations research that helps the decision maker to solve and evaluate problems related to multiple criteria [8]. These MCE techniques could be used for identifying the suitable crushing technique for the NCS production. This paper presents the use of fuzzy analytical hierarchical process (FAHP) integrated with elimination et choix traduisant la realité (ELECTRE I)-based MCE technique to identify the best crushing techniques among five alternatives using the 11 criteria covering various sustainable factors.

2. MCE MODEL DEVELOPMENT AND ANALYSIS

The selection of appropriate and sustainable crushing method for plant mode NCS production consists of three essential phases with mutually complementing output of each phase. These are (1) identification of evaluation criteria and alternatives, (2) computation of criteria weights using FAHP and (3) ranking the alternatives using ELECTRE I. The schematic diagram of methodology adopted for the selection of the best crushing method for maximum production NCS is shown in Figure 2. The following sections describe this MCE model development and associated anlyses.

2.1. Identification of evaluation criteria and alternatives

Initially, after identifying several sustainable criteria through field and literature surveys and following 'combining and separation of criteria' processes as laid out by the classical principles of MCE, a comprehensive list of the 11 evaluation criteria has arrived. The identified 11 evaluation criteria, their definitions and their nature (maximization or minimization, crisp or fuzzy) are described in the Table 1. After a thorough literary investigations and field studies on the crushing practices being followed in the NCS production as well as in sugar industries, five crushing methods are found to be the methods that may be considered to improve the present crushing processes for the NCS production.These are (i) vertical crushers that run on electical power (CM_1), (ii) horizontal crushers that run on electical power (CM_2), (iii) horizontal crushers that run on diesel engine (CM_3), (iv) multi-horizontal crushers that run on electical power (CM_4) and (v) multi-horizontal crushers that run on electrical power with hot water application (CM_5). On-sight pictures of three crushing methods (CM_1–CM_3) obtained during field studies carried out at various NCS plants in Anakapalle, Andhra Pradesh, India, are as shown in Figure 3. Description of these alternatives along with the other two alternatives is as given hereunder.

In single vertical (CM_1) and horizontal crushers (CM_2) that are operated on electrical power, the three rollers are arranged vertically and horizontally, respectively, in the form of a triangular tandem operated by means of electric power. These two alternatives require comparatively less energy and capital cost and also relatively less extraction efficiency ranges about 50% and 55–60%, respectively [5]. The alternative CM_3 is similar to alternative CM_2 in roller arrangement, but operated by means of diesel and the extraction efficiency ranges ~50–55% [5]. Similarly, for alternative CM_4, multiple horizonatal mills (two or three mills) are arranged in series each with three fluted rollers operated by means of electrical power and whose extraction efficiency ranges between 65% and 70% [6]. Alternative CM_5, widely used in the sugar industry is more similar to the alternative CM_4; however, the juice extraction is done with the addition of hot water, whose extraction efficiency ranges between 75% and 80% [6,7]. All these techniques of juice extraction vary with each other according to the usage of type and number rollers, the primary source of energy used to operate the crusher and the use of hot water to increase juice recovery.

2.2. Computation of criteria weights using FAHP

The FAHP method is applied to derive weights for each criterion. In this method, primarily a FAHP model is estabished by

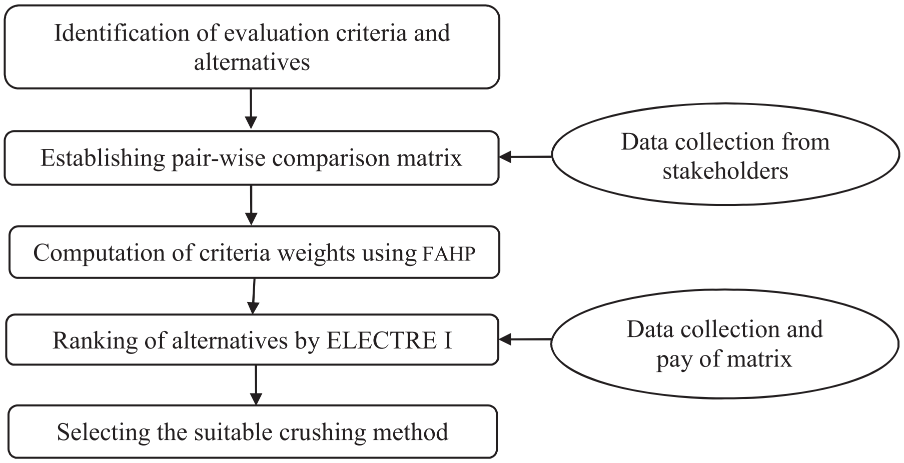

Figure 2. *Methodology adopted for the selection of the best crushing method for maximum production NCS.*

Table 1. *Evaluation criteria.*

	Evaluation Criteria	Definition	Max/min.	Crisp/fuzzy
EC_1	Water usage (lit)	The amount of water required in juice extraction process to get the desired sugarcane juice	Min	Crisp
EC_2	Energy required (kWhr)	The energy required to crush 1 ton of sugarcane	Min.	Crisp
EC_3	Working hours (hrs)	The time taken by total number of workers to carry out the crushing process for 1 ton of cane	Min.	Fuzzy
EC_4	CO_2 equivalent emissions (kg CO_2e/kwh)	The direct or indirect CO_2 equivalent emissions emerged out during crushing process	Min.	Fuzzy
EC_5	Energy cost (INR)	The cost incurred on the energy required for crushing process to crush one ton of cane	Min.	Crisp
EC_6	Machinery cost (INR)	The cost of crushing mills and other equipment to extract the maximum amount of juice from 1 ton of cane	Min.	Crisp
EC_7	Crushing time (min)	The total time period to convert one ton of sugarcane into sugarcane juice	Min.	Fuzzy
EC_8	Maintenance cost (INR)	The cost incurred to keep the machinery and other equipment in good working conditions	Min.	Fuzzy
EC_9	Extent of automation (LOA)	The level to which the juice extraction process is automated (rated on a scale of 1–5)	Max.	Fuzzy
EC_{10}	Amount of the juice extracted (kg)	The quantity of juice extracted from sugarcane through the crushing process	Max.	Crisp
EC_{11}	Concentration of juice (° Brix)	The sugar content of cane juice for 1 ton of cane	Max.	Crisp

(i) (ii) (iii)

Figure 3. *Current practice of crushing techniques observed during field studies: (i) vertical crusher operated by electrical power (CM_1), (ii) horizontal crusher operated by electrical power (CM_2) and (iii) horizontal crusher operated by diesel engine (CM_3).*

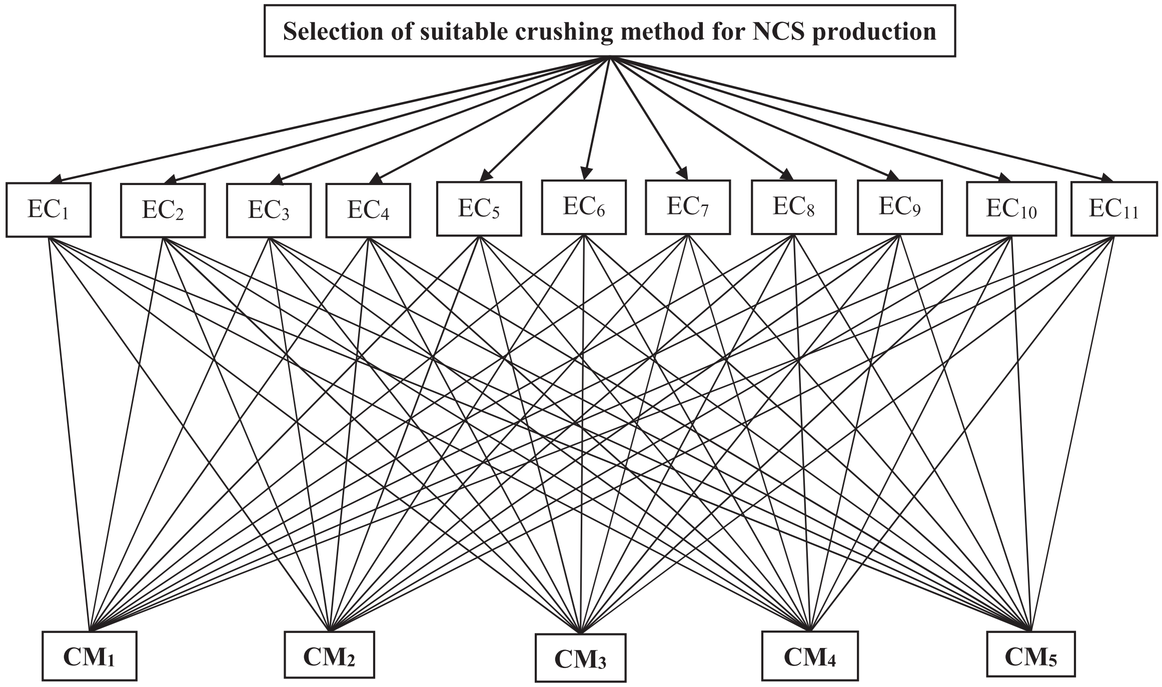

Figure 4. *Decision hierarchy of the crushing method selection.*

arranging the objective at the first level of hierarchy, evaluation criteria at the second level and alternative at the third level. The decision hierarchy for the present decision problem is shown in the Figure 4.

One of the requirements to get the criteria weights using FAHP is to have a pairwise comparison matrix of all the criteria. Saaty's nine-point scale of relative importance is used for generating this pairwise comparison matrix by comparing each criteria with the other [9]. This information has been obtained from three stakeholders groups viz. sustanability and academic promotors, NCS manufacturers and NCS plant equipment manufacturers through personal interactions during field studies conducted on 6–12 March 2019 at a study area viz. Anakapally, Andhrapradesh, India. Whenever there is a fuzzyness involved in the data, MCE theories suggest to use fuzzy-based techniques to take care of the problem. Since some of the criteria are fuzzy in nature and the decisions given by the stakeholders could be incomplete, imprecise and fragmented, the pairwise comparison matrix is fuzzified using triangular fuzzy membership functions. Then, the geometric mean method of Buckley is used to build a comprehensive pairwise comparision matrix and to compute the criteria weights [10]. The comprehensive pairwise comparison of the 11 criteria with respect to the overall objective by three decision makers is aggregated in the Table 2. Based on this aggregated pairwise comparison matrix, the criteria weights are computed.

2.3. ELECTRE I computations for ranking alternatives

The ELECTRE method was developed by Bernard Roy [11]. This method appears in the models viz. ELECTRE I, II, III, IV, IS and TRI. Each model is based on the same background but operates in different ways [12]. The method is characterized by thresholds and the outranking notion. In view of its simplicity and its wide applicability in a wide range of energy and sustainability problems, ELECTRE I is selected as the MCE technique for the present analysis [13].

The method of ranking the alternatives starts with formulating a data matrix that contains the performance of alternatives with reference to the criteria. Table 3 presents this data matrix for five crushing methods with respect to the 11 evaluation criteria for crushing 1 ton of sugarcane. The required data for alternatives CM_1–CM_3 was obtained through published literature [2,6,14,15] and field studies carried out during 6–12 March 2019 at the study area viz. Anakapally, Andhrapradesh, India. For the alternatives CM_4 and CM_5, the data was obtained through literature sources [6,7,15] and personal discussions with the technical managers at NSL Krinshnaveni Sugar Ltd in Telengana, India.

The data for each criteria given in Table 3 is self-explanatory when looked in conjunction with the definitions of the criteria given in Table 1. The maintenance cost is estimated by considering the labour charges, the service charges required for re-sharpening the crusher blades and other miscellaneous expenditure, as per the information received during field studies and further confirmed by the information given by Ramarao [14] and Malkunje [15]. For instance, the computation of the maintenance cost for alternative CM_1, as detailed below. From the field survey, it was noted that 4 manhours are required at a rate of Rs. 37.5 per manhour. The field survey also indicated that the crusher blades are to be re-sharped every 3 months costing around Rs.

Table 2. *Comprehensive pair-wise comparision matrix.*

	EC_1	EC_2	EC_3	EC_4	EC_5	EC_6	EC_7	EC_8	EC_9	EC_{10}	EC_{11}
EC_1	(1,1,1)	(0.17,0.21,0.28)	(0.19,0.24,0.31)	(0.63,0.95,1.26)	(0.15,0.18,0.22)	(0.13,0.14,0.17)	(0.21,0.26,0.37)	(0.5,0.7,1)	(0.17,0.21,0.28)	(0.14,0.16,0.2)	(0.24,0.32,0.5)
EC_2	(3.63,4.72,5.77)	(1,1,1)	(0.69,1.06,1.44)	(0.63,0.95,1.26)	(0.4,0.61,0.91)	(0.17,0.21,0.26)	(0.55,0.69,0.91)	(1.82,2.38,3.3)	(0.87,1.22,1.59)	(0.35,0.44,0.55)	(1.39,1.71,2.08)
EC_3	(3.17,4.22,5.24)	(0.69,0.94,1.44)	(1,1,1)	(3.63,4.72,5.77)	(1.17,1.55,2)	(0.19,0.24,0.31)	(1,1.44,2)	(2.88,4.12,5.24)	(1.26,1.71,2.29)	(0.41,0.63,1)	(1.44,1.88,2.47)
EC_4	(0.63,1.05,1.59)	(0.173,0.21,0.26)	(0.17,0.21,0.28)	(1,1,1)	(0.22,0.28,0.4)	(0.15,0.17,0.2)	(0.44,0.52,0.63)	(0.66,0.81,1.04)	(0.48,0.57,0.69)	(0.3,0.36,0.42)	(0.5,0.62,0.79)
EC_5	(4.58,5.6,6.6)	(1.1,1.65,2.52)	(0.5,0.64,0.85)	(2.52,3.56,4.58)	(1,1,1)	(0.16,0.19,0.24)	(0.58,0.75,1)	(2.08,3.3,4.33)	(1.47,1.84,2.29)	(0.48,0.58,0.72)	(1.26,1.65,2.11)
EC_6	(6,7,8)	(3.63,4.72,5.77)	(3.17,4.22,5.24)	(5.01,6,6.87)	(4.16,5.28,6.35)	(1,1,1)	(3.3,4.38,5.43)	(6,6.8,7.56)	(3.91,5.01,6.07)	(2.29,3.42,4.48)	(3.91,5.01,6.07)
EC_7	(2.71,3.78,4.82)	(1.39,1.44,2.88)	(0.5,0.69,1)	(1.59,1.91,2.29)	(1,1.34,1.71)	(0.18,0.23,0.3)	(1,1,1)	(3.91,5.01,6.07)	(0.93,1.36,1.82)	(0.218,0.28,0.4)	(1,1.49,2.08)
EC_8	(1,1.44,2)	(0.3,0.42,0.55)	(0.19,0.24,0.35)	(0.96,1.233,1.51)	(0.23,0.3,0.48)	(0.13,0.15,0.17)	(0.16,0.2,0.26)	(1,1,1)	(0.38,0.49,0.63)	(0.16,0.19,0.23)	(0.30,0.43,0.57)
EC_9	(3.63,4.72,5.77)	(0.63,0.82,1.14)	(0.44,0.58,0.79)	(0.44,0.58,0.79)	(0.44,0.54,0.68)	(0.16,0.2,0.26)	(0.55,0.74,1.08)	(1.59,2.03,2.62)	(1,1,1)	(0.35,0.51,0.72)	(1.25,1.61,2)
EC_{10}	(5.24,6..26,7.27)	(1.82,2.27,2.89)	(1,1.59,2.47)	(1,1.59,2.47)	(1.39,1.71,2.08)	(0.22,0.29,0.44)	(2.52,3.56,4.58)	(4.331,5.31,632)	(1.39,1.96,2.88)	(1,1,1)	(2.29,3.48,4.58)
EC_{11}	(2,3.11,4.16)	(0.48,0.58,0.72)	(0.41,0.53,0.69)	(0.41,0.53,0.69)	(0.48,0.61,0.79)	(0.16,0.2,0.26)	(0.48,0.67,1)	(1.75,2.32,3.3)	(0.44,0.52,0.63)	(0.22,0.29,0.44)	(1,1,1)

1200 per one sharpening that translates in to Rs. 5 for crushing 1 ton of sugarcane (which can be crushed in 2 hours). The NCS industry is a cottage industry with low capital investments and the capital investments for the crushers alone is further lower, as observed from the Table 3. It is also noted during the field and literature studies that the salvage value of the crusher after its lifetime (20–25 years) is very low. The investor goes for a fresh piece of equipment with cash purchases, not bothering much about the financial elements such as discount rates and depreciation during the lifetime of crusher, possibly because of the low capital investments involved. However, to take care of these and other exigencies associated with the hardware, in the current analyis, an additional Rs. 8/ton of cane has been considered as the miscellaneous expenditure under maintenance cost. Similar computations were carried out for other alternatives to arrive at the figures mentioned in Table 3.

Figure 5 illustrates the logical procedural steps of ELECTRE I for ranking the five crushing alternative [16]. Initially, the data matrix is normalized to convert different units of various criteria into a common measurable unit. Then, the weighted normalized decision matrix is constructed to determine the concordance set and discordance set. Further, the net superior and inferior value are computed and the alternatives are ranked according to decreasing order of net superior value and increasing order of net inferior value.

3. RESULTS AND DISCUSSION

The comprehensive data have been generated using MS EXCEL spreadsheet. Computed weights of all 11 criteria are as illustrated in Table 4. As required by the FAHP computation methodologies, the consistency ratio (CR) was computed and was found to be 0.075 thereby satisfying the requirement of CR to be less than 0.1. It can be observed from the weightages that the machinery cost takes the highest importance in deciding the suitability of crusher for the NCS production. Followed by this, are the criteria viz. amount of juice extracted, working hours, energy costs. With its weightage of 0.022, water usage to improve the quantity of juice has become less important in deciding the suitable crushing method for the NCS production. These computed weightages are used as inputs for the earlier described ELECTRE I-based MCE technique for ranking juice extraction alternatives for the NCS production.

To take up the further steps in the ranking process using ELECTRE I, the weighted normalized decision matrix is computed by considering the normalized matrix. Table 5 presents the weighted normalized decision matrix. Based on this weighted normalized data matrix and by considering the condition for concordance and discordance interval sets, the concordance and discordance matrix is obtained and are tabulated in the Table 6 and Table 7, respectively. Further, the net superior value and the net inferior values are calculated using Equation 4 in the Figure 5 and are tabulated in Table 8.

Table 3. *Data matrix for crushing one ton of sugarcane.*

Evaluation	Criteria	Alternatives				
		CM_1	CM_2	CM_3	CM_4	CM_5
EC_1	Water usage (lit)	0*	0*	0*	0*	300*[7]
EC_2	Energy required (kwhr)	8*	5*	4*	15*	15[7]
EC_3	Working-hours (hr)	4*	2*	2*	2.5*	0.6[7]
EC_4	Co_2 equivalent emissions (kg CO2e/kwh)	11.38*	7.11*	5.67*	21.34*	21.34[7]
EC_5	Energy cost (Rs.)	37#	32#	230#	90#	90#
EC_6	Machinery cost (Rs.)	1,55,000*[14]	1,50,000*[14]	1,60,000*[14]	4,50,000[6]	10,00,000[7]
EC_7	Crushing time (min)	90*	40*	40*	45*[5]	35*[7]
EC_8	Maintenance cost (Rs.)	163*[14,15]	155*[14,15]	174.8*[15]	224.4*[15]	150*[15]
EC_9	Extent of automation (LOA)	1*	2*	2*	3*	5*
EC_{10}	Amount of the juice extracted (kg)	540*[6]	545*[6]	537.5*	650[6]	750[6]
EC_{11}	Concentration of juice (°)	20*[2]	20*[2]	20*[2]	20[6]	15[7]

* obtained data from field studie.
# Estimated based on present electricity/fuel cost.

Table 4. *Weight of criteria for selecting the suitable juice extraction method for the NCS production.*

Evaluation criteria	Criteria weights
EC_1	0.022
EC_2	0.077
EC_3	0.105
EC_4	0.032
EC_5	0.090
EC_6	0.295
EC_7	0.084
EC_8	0.029
EC_9	0.066
EC_{10}	0.148
EC_{11}	0.053

Table 5. *Weighted normalized data matrix.*

	EC_1	EC_2	EC_3	EC_4	EC_5	EC_6	EC_7	EC_8	EC_9	EC_{10}	EC_{11}
CM_1	0	0.340	0.723	0.340	0.138	0.137	0.746	0.415	0.152	0.396	0.468
CM_2	0	0.212	0.361	0.212	0.120	0.133	0.332	0.395	0.305	0.399	0.468
CM_3	0	0.170	0.361	0.169	0.860	0.142	0.332	0.445	0.305	0.394	0.468
CM_4	0	0.637	0.452	0.637	0.337	0.399	0.373	0.572	0.457	0.476	0.468
CM_5	1	0.637	0.108	0.637	0.337	0.886	0.290	0.382	0.762	0.550	0.351

Table 6. *Concordance matrix.*

	CM_1	CM_2	CM_3	CM_4	CM_5
CM_1	0	0.251	0.636	0.597	0.568
CM_2	1	0	0.891	0.786	0.568
CM_3	0.438	0.438	0	0.697	0.478
CM_4	0.477	0.288	0.378	0	0.568
CM_5	0.432	0.432	0.522	0.630	0

Table 7. *Discordance matix.*

	CM_1	CM_2	CM_3	CM_4	CM_5
CM_1	0	0.823	0.438	0.477	0.432
CM_2	0.053	0.000	0.438	0.288	0.432
CM_3	0.636	0.891	0	0.378	0.522
CM_4	0.597	0.786	0.667	0	0.535
CM_5	0.568	0.568	0.478	0.653	0

Table 8. *Net superior and inferior value (C_a and d_a).*

Alternatives	C_a	d_a
CM_1	−0.059	0.063
CM_2	0.367	−0.372
CM_3	−0.075	0.081
CM_4	−0.200	0.158
CM_5	−0.034	0.069

As per the procedural requirement of ELECTRE I, the five crushing alternatives are sorted according to the decreasing order of net superior values and increasing order of the net inferior values. Figure 6 illustrates these final ranking patterns for the five alternate crushing methods. From Figure 6, it is observed that alternatives CM_3 (diesel-operated horizontal crushers) and CM_4 (electrical power-operated multi-horizontal crusher) would be the least preferred crushing methods for improving the NCS production. High machinery and energy cost, relatively a lesser amount of juice recovery are some of the possible reasons for its least preference for improving the NCS production. This means that the current practice of using diesel power-operated horizontal crushers is the most inferior option and hence should be dispensed away with, to improve the NCS production.

Also, it could be observed that CM_5 (electrical power-operated multi-horizontal crusher with application of hot water) and CM_1 (electrical power-operated single vertical crusher) are ranked 3 and 2, respectively, according to net superior values. On the other hand, the same alternatives are ranked 2 and 3, respectively, according to net inferior values. These suggest that both of the above alternatives are comparatively least preferred for improving the NCS production. The highest preferred alternative is CM_2 (electrical power-operated horizontal crushers). It is worth noting that, although the CM_5 option is quite widely

Step-1. Step-1. Normalizing the payoff matrix

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum a^2{}_{ij}}} \quad , j = 1, 2\ldots n;\ i = 1, 2\ldots.m \qquad (1)$$

Where, r_{ij} element of normalized matrix R of alternative j under the evaluation criteria i.

a_{ij} element of decision matrix of alternative j under the evaluation criteria i.

↓

Step-2. Construction of the weighted normalized decision matrix v_{ij} by multiplying the normalized decision matrix r_{ij} with its associated weight (w_i).

↓

Step-3. Determining concordance set (C_{ab}) and discordance set (Dab) (2)

$$C_{ab} = \{j|x_{aj} \geq x_{bj}\}\ ; D_{ab} = \{j|x_{aj} \leq x_{bj}\}$$

↓

Step-4. Calculate the concordance matrix by adding the values of weights of concordance set elements

↓

Step-5. Calculate the discordance matrix (3)

$$D_{ab} = \frac{\max_{j \epsilon D_{ab}} |v_{aj} - v_{bj}|}{\max_{j \epsilon j,m,n \epsilon i} |v_{aj} - v_{bj}|}$$

↓

Step-6. Calculation of net superior (C_a) and inferior (D_a) value. (4)

$$C_a = \sum_{b=1}^{n} C_{(a,b)} - \sum_{b=1}^{n} C_{(b,a)}\ ;\ D_a = \sum_{b=1}^{n} D_{(a,b)} - \sum_{b=1}^{n} D_{(b,a)}$$

Figure 5. *The stepwise procedure of ELECTRE I for ranking alternative.*

used in the sugar industry, this may not be suitable for the NCS production compared with CM_2 due to its high machinery cost, energy cost and CO_2 equivalent emissions. Similarly, electrical power-operated single vertical crusher, which is in current NCS production practice, may be used as an option in case the use of CM_2 is curtailed for any other reason. The reason for alternative CM_1 as a secondary option is due to its high energy requirement and crushing time. Though the alternative CM_2 extracts relatively small amount of juice, but then it satisfies all other sustainability criteria that improve the NCS production. Therefore, based on this, some of the maximization and minimization criteria of five alternatives, the undertaken FAHP-integrated, ELECTRE I-based MCE suggest that electrical power-operated single horizontal crusher is the most suitable and sustainable juice extraction method among the current practices.

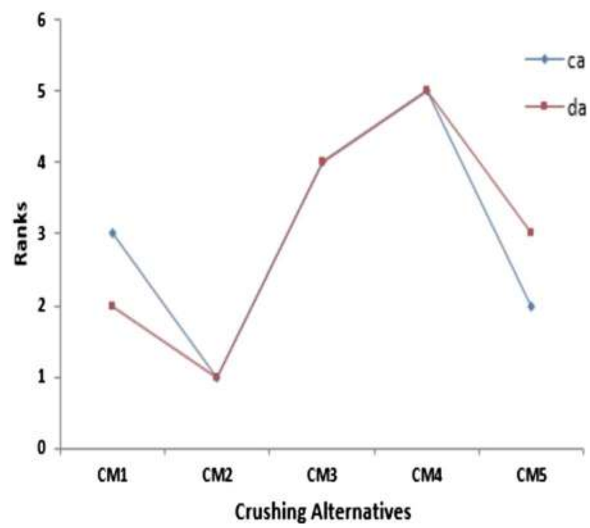

Figure 6. *Ranking of crushing method alternatives.*

4. CONCLUSIONS

In this paper, the suitable crushing method for NCS production is identified based on MCE technique. The undertaken field and literature surveys indicated that the best crushing technology is to be identified among five alternatives, with respect to the 11 criteria covering various sustainability factors viz. technological, economic and environmental factors. The selection of the most suitable crushing method for improving the NCS production is a complex task because of multiple criteria involved and hence identified that MCE techniques could be used for this. In this paper, FAHP–ELECTRE I is used for determining the most suitable crushing technology. The undertaken analyses indicate the following:

- Among the identified 11 criteria, machinery cost and amount of juice extracted are the most important criteria in selecting the suitable crushing method for improving the NCS production.
- ELECTRE I is chosen to be the suitable technique for the crushing technique selection and the evaluation conclude that electrical power-operated horizontal crushers is the most appropriate and sustainable crushing method for the NCS production.
- On the other hand, the current practice of using diesel power-operated horizontal crushers is the least preferred alternative for the NCS production.
- The model and methodology used here suggest that similar MCE techniques can be attempted to identify the best alternatives in the sub-processes to improve the NCS production.

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