Application of Hybrid Metaheuristic Optimization Algorithm (SAGAC) in Beef Cattle Logistics

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Abstract. The study objective was to evaluate the performance of SAGAC in optimizing a linear mathematical model in whole variables to determine the most cost-effective solution in transporting cattle for slaughter. The model determines the choice of refrigerator truck, road (route), and an open-truck in a scripting process. The tests performed with the SAGAC algorithm for optimizing the proposed model were compared with the results obtained, under similar conditions, by the branch-and-bound method for solving entire problems and solving a problem optimally. After the first twenty-two experimental trials, for comparison between the two methods, nine more experimental trials were carried out, with an increase in the degree of complexity, only with the SAGAC algorithm. The results obtained in the first twenty-two experimental trials demonstrate an equivalent performance between the two methods, showing that the SAGAC algorithm, even though it is not a technique that guarantees optimal results, in this case, was also able to find them. The nine final experiments performed only by SAGAC showed satisfactory results, with an evolutionary curve of exponential behavior.

Keywords: Meat production, Optimization, Algorithm, Logistics, Transportation

1 Introduction

Brazil has a substantial production capacity in agricultural activity sectors due to the available agricultural area. A large part of Brazilian agribusiness production represents an important share in the country's GDP and the balance of our exports, where agriculture has fundamental importance.

Brazil is the world's largest exporter of beef. Health control, knowledge and technology, and the country's natural aspects are pointed out as the keys to this product's success in the market [9]. The development of the food sector and market causes numerous organizational changes and structural in the chain, acting on the agents of production, transformation, trade, and distribution.

As a significant exporter of agribusiness products, Brazil's position has ensured the intense professionalization of the main objective of meeting markets' requirements with high safety standards, such as Europe and the United States. About 150 countries import Brazilian products of animal origin. Of a total of around US$16 10^9 of Brazilian exports in 2018, nearly 45% is beef, 42% chicken meat, 10% pork, and 3% other types of meat such as turkey, goose, sheep, and duck [8]. Brazilian meat production from 1994 to 2016 presents an increase in cattle, pork, and chicken production of 85% (nearly 3% per year), 162% (4% per year), and 285% (6% per year), respectively [1].

A factor considered in beef cattle transportation is minimizing the animals' stress during the movement between the farm and the slaughterhouse. Transport might cause a decrease in the meat's quality due to possible injuries caused by the vehicles' displacement and the stress of travel time [12].

Up to 3% of the live animal's weight loss occurs in the loading and unloading procedure, one of the main losses in the first hours and kilometers traveled in the transport [2]. The size of the animals, the type of truck used for transportation, the distances between the points of origin and destination (routes), the state of conservation of the road pavement, and the use of trucks with greater load capacity are the main determining factors of hematoma causes [6]. Other factors causing damage to animals' carcasses during transport for slaughter, such as transport cost, carrier density, loading, and accidents with vehicles, have also been studied [7].

The objective of this study is to compare the performance of the SAGAC hybrid metaheuristic algorithm with that of the Branch-and-bound [10] algorithm in a logistical process of routing cattle load from farms to slaughterhouses using trucks, determining the best possible combination of slaughterhouse factors, route, and truck that promotes the best value paid to producers.

2 Methods

2.1 Process model

The model presented in the sequence was proposed by Ribeiro et al. (2018). The data to detail the mathematical model and develop the computational tool capable of assisting the rural producer in the decision-making process are as follow:

N = Total number of cattle to be transported for slaughter; G = estimated weight of cattle (in arrobas); F = Number of slaughterhouses available for slaughter; R = number of routes that can be used for the transport of livestock; C = number of trucks available for the transportation of cattle; T = Number of trucks to be effectively used in cattle transport; CFi = Slaughter capacity of the slaughterhouse i (cattle heads); Ai = Price paid by the slaughterhouse i for each amount of cattle (Reals); Dj = Distance between the farm and the refrigerator by route j (km); REj = estimation of weight reducers (per km) for route j (%); CCk = capacity of truck k (cattle heads); RCk = estimation of weight reducers (per km) for truck k (%); Hk = Freight price of truck k (Reals).

The estimated price (Reals) is calculated (Eq. 1) for the payment of the cattle transported from the farm to the processing plant i using route j on the truck k:

$$P_{ijk} = GA_i - GA_iD_j\,(RE_j + RC_k) = GA_i\,(1 - D_j\,(RE_j + RC_k)) \quad (1)$$

Be y_{ijk} the binary decision variable defined by:

y_{ijk}={1 if the cattle are transported to the refrigerator ***i*** by route ***j*** using truck ***k*** and, 0 otherwise}.

The entire decision variable for the problem is given by x_{ijk}=number of cattle heads sent to the processing plant ***i*** by route ***j*** employing truck ***k.*** The mathematical model of whole linear programming for the problem is described in Eq. 2 through 9, namely:

Maximize: $f = \Sigma(Pijkxijk) - \Sigma(Hkyijk)$ (2)

Subject to:

$\Sigma xijk = N$ (3)

$\Sigma xijk \leq CFi$ (i=1..) (4)

$xijk \leq CCkyijk$ (i=1..,j=1..R,k=1..C) (5)

$\Sigma yijk \leq 1$ (k=1..) (6)

$\Sigma yijk = T$ (7)

$xijk \geq 0$ and $inte$ger (8)

y_{ijk}= 0/1 (9)

2.2 The hybrid metaheuristic algorithm (SAGAC)

The model is formed using two algorithms, the Simulated Annealing (SA) and the Genetic Algorithm (AG), with the inclusion of a mechanism (function) that promotes acceleration in the convergence (AGAC) of the obtained results. The SA algorithm acts on the generation of individuals who make up the modified genetic algorithm's initial population (AGAC). With the use of the SA algorithm, it is possible to have a good quality initial population composition, that is, pre-optimized individuals.

The routine behavior of the AGAC algorithm promotes Convergence Acceleration in which, after crossing, there is an assessment of the individuals (Sons) generated and a check for quality improvement concerning the individuals of the elite group of the population. If such development does not occur, the individual (s) of the offspring (ren) is (are) discarded, the individual (parent) of the worst quality is exchanged for another individual in the elite group who is closest and is better than the individual (Father) who was changed. After the individual's change (Father), a new crossing occurs for the missing child's generation (s). This sequence of steps will be repeated until both offsprings meet the criteria for improvement or the stipulated number of attempts is reached. Fig. 1 shows the flowchart of the SAGAC hybrid algorithm.

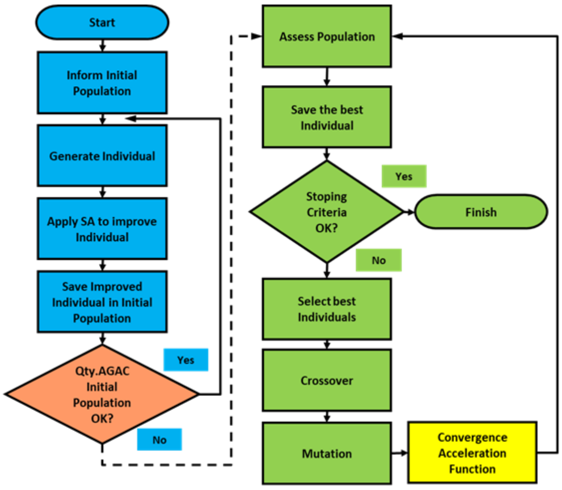

Fig. 1. Flowchart of the hybrid SAGAC algorithm

With each cycle of processing of the Simulated Annealing (SA) algorithm, the best result (individual) is stored to compose the initial population used by the modified Genetic Algorithm with convergence acceleration mechanism (AGAC).

2.3 Setup Parameters of SAGAC

In the case of SAGAC, the variables that influence the algorithm's behavior are its processing parameters [11, 8, 3].

Parameters of SA

1º. Initial Temperature = 100; it is the number of cycles that will be processed in an algorithm repetition loop;

2º. TDS = 1; it is related to the Temperature Decay Scheme - defines how the temperature is decreased and the number of iterations performed for each temperature.

- the Temperature Decay Function is represented in Eq. 10.

〖Temp〗_(i+1)= 〖Temp〗_i-1 (10)

- Number of Iterations at each Temperature = 1.

Parametersof AGAC

1st. Population size = 100; 2nd. Generations Qty. = 1000; 3rd. Elitism = 10%; 4th. Mutation = 7%; and, for the case of the Convergence Acceleration Genetic Algorithm (AGAC); 5th. Qty of attempts to generate children in the elite = 1.

The optimization experiments (maximization of the cattle transport payment) were carried out based on the results developed by [10]. Was performed computational tests with the mathematical model proposed for 22 problems of shipping cattle from slaughterhouses. In all tests, the number of refrigerators, the number of routes (or roads), and the number of trucks available were respectively 3, 4, and 5. The other data used related to the sign's price, the routes, the trucks, price reducers, and freight charges are shown in Table 1, in [10], 22 computational experiments.

Table 1. Data used in [10], 22 experiments.

Data					
N	60				
G	15				
F	3				
R	4				
C	5				
T	3				
Cfi	Cf1 = 40	Cf2 = 40	Cf3 = 40		
Ai	A1 = 120.00	A2 = 110.00	A3 = 130.00		
Rej	Re1 = 0.1	Re2 = 0.2	Re3 = 0.1	Re4 = 0.1	
CCk	CC1 = 12	CC2 = 12	CC3 = 12	CC4 = 24	CC5 = 28
RCk	RC1 = 0.03	RC2 = 0.03	RC3 = 0.03	RC4 = 0.02	RC5 = 0.01
Hk	H1 = 500.00	H2 = 500.00	H3 = 500.00	H4 = 500.00	H5 = 500.00

3 Results and Discussion

Analysis and comparison of the results obtained by SAGAC and those of other techniques used the optimize the same process.

Fig.4 shows the average convergence of the results obtained by SAGAC in the experimental trials. It represents the percentage of the evolution of the values obtained by the SAGAC method from the first Generation of the Genetic Algorithm to the last generation processed.

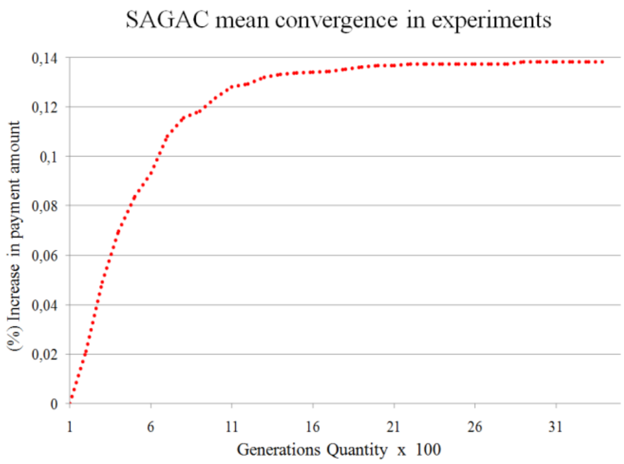

Fig. 2. Average convergence of the results obtained by the SAGAC method

Table 2 presents the results obtained by the two methods: branch-and-bound [10] and the SAGAC method. The first twenty-two results are sequenced descending because they are more easily located in their source [10]. The average of the results obtained between comparative tests (1 and 22) shows that the SAGAC algorithm presented a better performance (81.117,75) than that found by [10] (81.078,49). From experimental assay 23, the results data were obtained only by the SAGAC method.

Table 2. Comparative of the results obtained (Payment, $)

Assay	N	T	[10]	SAGAC	Comparison
22	12	1	18724.00	18724.00	0
21	19	1	29938.00	29938.00	0
20	20	1	31540.00	31540.00	0
19	26	1	41152.00	41152.00	0
18	33	2	51776.00	51686.00	-90
17	35	2	54944.00	54818.00	-126
16	38	2	56969.00	59516.00	2547
15	40	2	62864.00	62648.00	-216
14	47	2	72014.00	72522.00	508
13	52	2	79604.00	79932.00	328
12	54	3	82896.00	82896.00	0
11	58	3	88824.00	88824.00	0
10	60	3	91812.00	91812.00	0
9	65	4	99097.00	98839.00	-258
8	67	4	102139.00	101725.00	-414
7	70	4	106054.00	106054.00	0
6	72	4	108940.00	108940.00	0
5	75	4	113269.00	113269.00	0
4	78	5	117590.00	116954.30	-635.7
3	80	5	120476.00	119696.60	-779.4
2	84	5	125181.20	125181.20	0
1	86	5	127923.50	127923.50	0
23	90	6		135345.10	
24	100	6		149333.00	
25	110	6		162557.40	
26	120	6		174860.20	
27	130	7		188159.20	
28	140	7		199558.60	
29	152	8		213975.20	
30	176	9		241093.20	
31	204	10		273953.20	
Average between 1 and 22 tests			81.078.49	81.117.75	

Fig.5 shows the behavior of the results obtained by the SAGAC method in the thirty-one tests performed. The behavior of the SAGAC algorithm results indicates a correlation between the number of animals transported and the amount paid to producers according to the routes indicated by the SAGAC algorithm. Results obtained between experimental tests 1 and 22 by the SAGAC algorithm, which were compared with the results obtained by [10], have a degree of correlation of 99.97%. This correlation can be explained because the results presented by tests 1 to 22 were the optimum results or very close to the optimum. It can be inferred that the results obtained by the SAGAC algorithm between tests 23 and 31, which presented a degree of correlation of 99.94%, must be excellent or are very close to the optimum, thus confirming the excellent performance of the SAGAC algorithm.

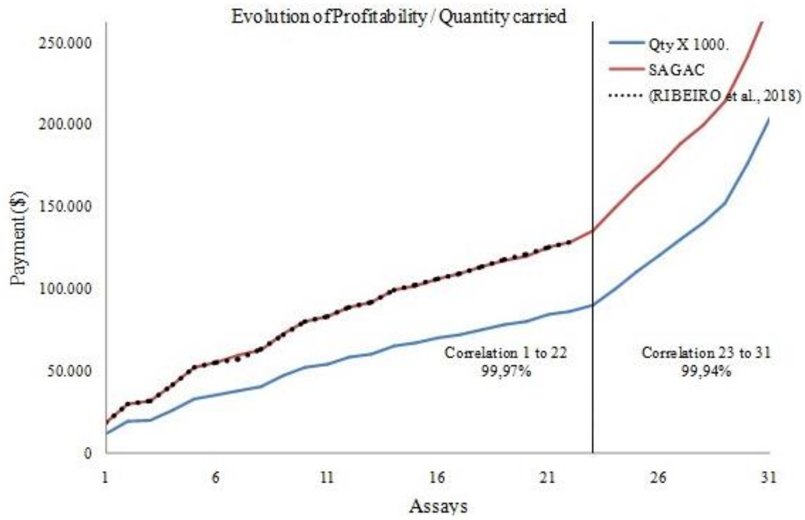

Fig. 3. The behavior of the data obtained by SAGAC in the 31 experimental trials.

4 Final remarks

A hybrid metaheuristic optimization algorithm (SAGAC) was presented in this work as an alternative to solve logistics problems, more specifically, the selection of the set of factors: refrigerator, route, truck, and quantity of cattle transported, in order to maximize the value of the payment to the producer. This algorithm can optimize combinatorial analysis problems in which the factual solution spaces are too large (NP-Hard), making the application of deterministic algorithms that, in turn, ensure an unfeasible optimal solution.

From the results performed by the SAGAC algorithm, in the twenty-two comparative trials with the branch-and-bound deterministic algorithm, SAGAC obtained a higher mean difference of 0.14%. Nine experimental trials (from 23 to 31) with a higher degree of complexity were conducted. The resultant data showed exponential progression with an $R^2 = 0.927$, suggesting that profitability increases when the number of cattle transported increases.

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