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Research Article

Green Fuzzy Tourist Trip Design Problem

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The shift from mass tourism to more personalized travel denotes great importance in the construction of tourist itineraries. Given the negative impacts of transport and tourism on the environment, sustainability criteria play an important role. The Tourist Trip Design Problem is related to the design of itineraries for tourists. Planning is complex in tourist regions of developing countries where the information associated with tourist activities is difficult to access, vague, and incomplete. With this information, tourists must plan their trip, and the conditions and limitations they establish for it are flexible and imprecise. Fuzzy optimization can address problems with this type of information and constraints. Therefore, in this paper, an analysis of the tourism supply chain is carried out, taking as a case study the Department of Sucre on Colombia's Caribbean coast. A Multiconstraint Multimodal Team Orienteering Problem with Time Windows and fuzzy constraints is developed to model the tourism trip design problem that maximizes profit and minimizes CO_2 emissions. The model is tested using datasets from the literature and the real world. The results demonstrate consistency with the fuzzy approach and generate a set of low-emission solutions.

1. Introduction

Tourism has a direct relationship with the economic growth of countries [1]. The growth of tourism has been constant in the first decades of the 21st century. According to data from the World Tourism Organization, international tourist arrivals worldwide grew 4% in 2019 to reach 1.5 billion [2]. Until 2020, world tourism suffered its worst year on record, with international arrivals falling 74%, because of COVID-19 [3]. The pandemic generated by the novel coronavirus SARS-CoV-2 negatively impacted the different economic activities derived from tourism. These impacts affect organizations' socioeconomic well-being, direct and indirect employees, and other stakeholders in the tourism supply chain (TSC). Despite the various economic complications, the pandemic suggests an opportunity to reinvent and rethink tourism [2]. This opportunity is relevant for all countries with tourism potential, such as Colombia.

The vulnerability of regions, organizations, and people has become evident after COVID-19, which needs to change unexpectedly from one day to the next. In logistics and transport, new models and innovative trends emerge. The effects of COVID-19 on supply chains are evident, and complex supply and distribution planning problems emerged to be solved [3, 4]. Relevant and emerging problems, such as humanitarian logistics for disaster emergencies, city logistics, green logistics, and tourist travel logistics, demand flexibility and dynamism due to their high uncertainty and the requirement to be addressed with soft computing methodologies [5].

The COVID-19 crisis adds to various logistics problems that interfere with the collaborative work of the TSC and affect its competitiveness. In Colombian regions, such as Sucre on the north Caribbean coast, the supply and access to tourism information in real-time are very limited due to the lack of structure and what the organization of the value offer. The lack of data limits the construction of decision-making tools to be used by all stakeholders, especially tourists and their itinerary planning [6]. The planning of tourist itineraries requires real and updated databases that provide accurate information on access to points of interest (POI). The information should include travel times, distances between POIs, and modes of transportation, among others, to facilitate decision-making and tourist planning, even under uncertainty [7]. In the real world, various data associated with the tourism planning process are uncertain (e.g., travel times by mode of transport, POI visit times, waiting times, and budgets) [8]. These data can be categorized as vague, ambiguous, limited, and imprecise in decision-making and can be approached as fuzzy sets [9]. Additionally, it is very complex to deal with uncertainty under stochastic parameters due to the lack of data that would allow a complete analysis and the construction of distributions [10]. Different methodological approaches are applied to address the uncertainty and its associated complexity. With them, it is not necessary to determine the distribution of the parameters with uncertainty, as are robust optimization, possibilistic programming, fuzzy programming, and credibility theory [11–13].

For a long time, the main objective of transport and tourism activities has been to maximize economic profitability and therefore reduce costs. Today, there is a common demand to address the negative impacts on the environment of these activities. On the way to a more sustainable economy, a green economy, sustainable tourism plays an essential role with significant challenges [14]. Tourism-related activities generate high CO_2 emissions into the environment [15]. Consequently, it is necessary to focus on the development of sustainable tourism based on the contribution to the achievement of the Sustainable Development Goals (SDGs). CO_2 emissions cause reactions associated with climate change [16], and the tourism is very sensitive to climate change [17]. Therefore, tourism management, from the perspective of itinerary planning, should focus on tourism with more environmentally friendly routes.

Decisions regarding tourism should help reactivate the economy by solving various latent problems of the TSC, such as itinerary management. Therefore, the aim of this paper is twofold. On the one hand, to diagnose the value offered to structure and define the TSC in the Department of Sucre, Colombia; to identify the POIs and their categorization according to the type of tourism; finally, to generate databases (instances) with information for the construction of decision-making models; on the other hand, to propose and solve a fuzzy mixed-integer linear programming model to design personalized tour itineraries with considerations of emissions. The remainder of this paper is structured as follows. Section 2 presents a brief review of the literature. Section 3 shows the development of the fuzzy mathematical model. Section 4 structures the supply chain of the case study. Section 5 presents the computational results. Finally, Section 6 presents the conclusions.

2. Overview of Related Literature

2.1. Tourism Supply Chain. Tourism as a heterogeneous sector of the economy is dynamic and complex [18]. Therefore, the structure of the TSC includes public and private organizations that provide different products and activities such as transportation, accommodations, food, and tourist attractions [19]. Tourism infrastructure is a key point in the development of the sector. The infrastructure supports the destination and can define its attractiveness [20]. A marked peculiarity of tourism is that the services and products offered are fixed, while the consumers (tourists) are mobile [18]. According to [19], the TSC has five echelons: first-tier suppliers, second-tier suppliers, travel agents, tour operators, and tourists.

2.2. Tourist Trip Design Problem. The Tourist Trip Design Problem (TTDP) is generally modeled as an Orienteering Problem (OP) or a Team Orienteering Problem (TOP) [7, 9]. The TTDP consists of building a travel itinerary to visit a set of POIs without exceeding the budget and maximizing the benefit [21]. Several variants have been added to the models to make them more realistic. These include time windows (TW), multiple constraints (MC), multiple transport modes (MM), and even uncertain parameters. The Team OP with TW has been extensively studied in the literature. For the rest of the variants reviewed here, and in addition to the criterion of realism and, therefore ,complexity, seminal and more recent papers have been selected. More papers have been reviewed in previous surveys [22–25].

Multiconstraints are extensions generally associated with simple or multiple time windows, budget limitations, itinerary duration, visits to certain types of POIs or limits on them, different benefits in POIs, etc., and aspects that restrict the route. In [26], a Multiconstraint Team OP with TW (MC-TOPTW) is evaluated. In [27] and later [28] an extension that adds multiple time windows (MCTOPMTW) where some POIs may have one or more time windows is solved. Fomin and Lingas [29] present an extension of the OP, the Time Depend Orienteering Problem (TDOP), where the time needed to travel between POIs depends on the departure time. This approach can be adapted to deal with the use of different modes of transport. For transport selection, in [30], a model is developed that considers the transport mode's choice to move between POIs. Similarly, [31] applies a multimodal Team OP with Time Window (MM-TOPTW) to design tourist routes.

On the other hand, uncertainty can be treated as stochastic or fuzzy depending on the nature of the problem or the data [32]. However, determining stochastic parameters presents a certain degree of difficulty if the required data are not available [10]. Therefore, fuzzy linear programming (FLP) represents a more appropriate way to deal with uncertainty when data are vague, ambiguous, and imprecise [9, 33]. Fuzzy optimization for decision-making has been used in recent years generating several contributions to deal with uncertainty [34]. The fuzzy set theory allows the transformation of linguistic variables into numerical variables [35]. Linguistic variables describe vague and imprecise printed information (e.g., at least 5) [36]. Thus, fuzzy optimization makes it possible to deal with such ambiguities in human reasoning without using rigid mathematical calculations [37]. Fuzzy models and solution techniques have been developed in the TTDP. The early work considers a fuzzy routing problem for sightseeing [38]. [9] developed a Fuzzy Greedy Randomized Adaptive Search Procedures (GRASP). The algorithm restricts the inclusion of POIs from the candidate list to the route according to their score, where the score is a fuzzy parameter. References [39, 40] applied a GRASP to solve a TTDP with Clustered POIs (TTDP-Cu) with objective function and fuzzy travel time constraints. More recently, Liao et al. [41] presented a TTDP in a fuzzy environment, which uses a model based on an approximate approximation to deal with fuzzy variables.

Tourism is responsible for 8% of global greenhouse emissions [42]. Transport and its negative externalities, especially pollution, directly affect tourist activities. The green concept applied to transport and the supply chain has recently emerged in the agendas and roadmaps associated with sustainable development and concerns about the environment and climate change. In route planning, the green problem literature is expanding. The term green is broad and applies to three categories of problems and models: green routing, which optimizes power consumption; pollution routing, which optimizes aspects related to pollution and CO_2 emissions; and finally, everything that has to do with reverse logistics planning, including waste collection [43]. United Nations World Tourism Organization evidences the CO_2 emissions from tourism and the implications of the different modes of transport [44]. A key development strategy that contributes to reducing climate change is to achieve green or sustainable tourism, which must minimize the amount of carbon dioxide emitted into the atmosphere. Therefore, designing more respectful itineraries of the environment is crucial to sustainable tourism. CO_2 emissions from tourism activities lead to a rethinking of tourism towards sustainable tourism. However, the development of environmentally friendly TTDPs is scarce in the literature. However, this concept in transportation and transportation routes has been widely disseminated and extensively researched in recent years, as verified in this paper's literature review [45]. Ref. [46] developed a model that considers CO_2 emissions in the design of tourist itineraries. The problem focuses on finding the shortest route that minimizes emissions. The problem is solved with dynamic programming. Ref. [47] also considered the CO_2 consumption in the construction of group routes. Finally, in [48], the uncertainty of parameters, such as travel time and tourist budget, is considered in addition to emissions. Also, in [49], a realistic itinerary recommendation framework is presented, modeled with multiple objectives with criteria of equity and social and environmental benefits for tourist groups. Taking into account the review of the literature carried out, the main contributions of this research are summarised in the following:

(i) The characterization of tourism and the availability of tourist data sets for Sucre: These will help build models to improve decision-making.

(ii) A new, more realistic, and complete mathematical model to design tourist itineraries: This model captures multiple problem constraints associated with time and cost. In addition, the model is bio-objective, considering among its criteria the reduction of emissions related to the choice of transport mode (multimodal)—a contribution to the scarce literature on the green TTDP.

(iii) The model considers the uncertainty in times and costs, modeling vague and imprecise constraints as fuzzy constraints.

(iv) The proposed methodology (fuzzy optimization) solves and finds multiple solutions for the model, using various tolerance values and the Pareto frontier analysis. Therefore, the set of optimal solutions is consistent with the fuzzy and multicriteria nature of the problem.

3. Mathematical Model

The TTDP is modeled as a Fuzzy Multiconstraint, Multimodal Team Orienteering Problem with Time Windows. The model aims to maximize the total profit P_i based on the number of routes k and minimize the cost of CO_2 emissions. There are a maximum travel time $T\max$ and a maximum travel budget P. Each node must be visited within a time window $[a_i, b_i]$, and the movement between POIs is selected from a set m of transport modes. The model notations are presented in Table 1. The mathematical model presents a biobjective function that maximizes profit and minimizes CO_2 emissions.

3.1. Biobjective Function.

$$\mathrm{Max} Z = \gamma \sum_{i=1}^{I} \sum_{k}^{K} P_i Y_{ik} \varphi + \beta \left(- \sum_{i}^{I} \sum_{j}^{I} \sum_{k}^{K} \sum_{m}^{M} ce\mathrm{E}_{ijkm} \right), \quad (1)$$

subject to

$$\sum_{j=1}^{I} X_{ijk} = \sum_{j=1}^{I} X_{jik} = G_k \forall i \in I^0, \quad \forall k \in K, \quad (2)$$

$$\sum_{j}^{I} X_{ijk} = G_k \forall i \in I^0, \quad \forall k \in K, \quad (3)$$

$$\sum_{k}^{K} Y_{ik} \leq 1, \quad \forall i \in I \backslash \{0\}, \quad (4)$$

$$\sum_{i=1, i \neq h}^{I} X_{ihk} = \sum_{j=1, j \neq h}^{J} X_{hjk} = Y_{hk \forall h \in I, \forall k \in K}, \quad \forall h \in I, \forall k \in K, \quad (5)$$

$$\sum_{m}^{M} F_{ijkm} \leq 1, \quad \forall ij \in I\colon i \neq j, \quad (6)$$

$$\forall k \in K, \forall ij \in I\colon i \neq j, \forall k \in K,$$

Table 1: Index, parameters, and variables.

Index and parameters	Description	Variables	Descriptions
$i \in I$	Set of POIs	Vc_{ijm}	Variable cost per distance traveled
I^0	Depot	φ	Profit-to-cost conversion parameter
$k \in K$	Set of routes	X_{ijk}	Binary variable. 1 if a trip is made in the arc ij on the route k, 0 otherwise
$m \in M$	Set of transport modes		
P_i	The score of POI	G_k	Binary variable. 1 if the route k is enabled, 0 otherwise
S_i	Visit time of POI		
T max	Maximum time of routes		
P	Maximum budget of routes	Y_{ik}	Binary variable. 1 if the POI i is on the route k, 0 otherwise
a_i, b_i	Time windows	F_{ijkm}	Binary variable. 1 if a trip is made in the arc ij on the route k with transport m, 0 otherwise
$co2_{ijm}$	Emissions matrix		
ce	Emissions cost	t_{ijm}	Travel time matrix

$$\sum_{m}^{M} F_{ijkm} = X_{ijk}, \quad \forall ij \in I\colon i \neq j, \forall k \in K, \tag{7}$$

$$\begin{gathered} T_{ik} + S_i + \sum_{m}^{M} t_{ijm} F_{ijkm} - T_{jk} \leq M\left(1 - X_{ijk}\right), \\ \forall ij \in I\backslash\{0\}\colon i \neq j, \forall k \in K, \end{gathered} \tag{8}$$

$$\sum_{i}^{I} S_i Y_{ik} + \sum_{j}^{J} \sum_{m}^{M} t_{ijm} F_{ijkm} \leq_f T \max, \quad \forall k \in K, \tag{9}$$

$$a_i \leq T_{ik} \leq_f b_i, \quad \forall i \in I\backslash\{0\}, \forall k \in K, \tag{10}$$

$$\mathrm{E}_{ijkm} = co2_{ijm} F_{ijkm}, \quad \forall ij \in I, \forall k \in K, \forall m \in M, \tag{11}$$

$$\sum_{i \neq j}^{I} \sum_{j \neq i}^{J} \sum_{m}^{M} F_{ijkm} Vc_{ijm} \leq_f P, \quad \forall k \in K, \tag{12}$$

$$\sum_{i=1}^{J} \sum_{k}^{K} X_{ijk} = K, \quad \forall j \in I^0, \tag{13}$$

$$\begin{gathered} X_{ijk}, Y_{ik}, F_{ijkm}, G_k \in \{1, 0\}, \quad \forall ij \in I, \forall k \\ \in K, \forall u \in U, \forall m \in M, \end{gathered} \tag{14}$$

$$T_{ik}, E_{ijkm} \geq 0, \quad \forall ij \in I, \forall k \in K, \forall m \in M, \tag{15}$$

The biobjective function (1) maximizes profit and minimizes CO_2 emissions generated by transportation. Constraints (2) ensure that the route starts and ends at the starting node. Constraints (3) guarantee that as many routes as allowed are made. Constraints (4) ensure that a POI is included in only one route. Constraints (5) have flowed. Constraints (6) and (7) determine the mode of transport on each arc. Constraints (8) calculate the travel times on each route. Constraints (9) ensure that the maximum travel time is not exceeded. Note that the f denotes that the constraint is fuzzy. Constraints (10) verify compliance with time windows and are fuzzy. Constraints (11) calculate the emissions at each arc. Constraints (12) guarantee compliance with the money budget, and the constraints also are fuzzy. Constraints (13) determine the number of routes to be performed. Finally, Constraints (14) and (15) define the nature of the variables.

To address uncertainty in this model, we use the fuzzy approach to address fuzzy constraints. A tolerance value τ by the decision-maker is added to the constraints (9), (10), and (12). $\alpha \in [0, 1]$ constitutes a range of variations that generate feasible solutions based on the problem's fuzzy nature [50]. The fuzzy set theorem representation is applied to obtain an auxiliary model *Maximize* $z = cx$ subjet to $Ax \leq b + \tau$ (1-α). The new constraints are as follows:

$$\begin{gathered} \sum_{i}^{I} S_i Y_{ik} + \sum_{j}^{J} \sum_{m}^{M} t_{ijl} F_{ijkm} \leq T \max \\ + \tau(1 - \alpha), \quad \forall k \in K, \end{gathered} \tag{16}$$

$$a_i \leq T_{ik} \leq b_i + \tau(1 - \alpha) \forall i \in I\backslash\{0\}, \quad \forall k \in K, \tag{17}$$

$$\sum_{i \neq j}^{I} \sum_{j \neq i}^{J} \sum_{m}^{M} F_{ijkm} Vc_{ijm} \leq P + \tau(1 - \alpha), \quad \forall k \in K, \tag{18}$$

4. The Case Study: Tourism Supply Chain in Sucre, Colombia

4.1. Study Area. The selected study area is the Department of Sucre, located in the northern region of Colombia (Figure 1) The Department of Sucre has excellent tourism potential associated with several tourism activities. However, the low competitiveness of the region [51] limits a positive response to the new dynamics of global tourism emerging, generated by a shift from mass tourism to an independent travel market under the new orientation of personalized tourism itineraries [52]. This last is of the highest relevance, considering the restrictions imposed by social distancing measures to respond to COVID-19.

4.2. Characterization of Tourism in Sucre. In Sucre, the inventory of attractions belonging to the tourist route of the Golfo de Morrosquillo and Sabana presents diverse zones of

Figure 1: Location of the Department of Sucre, Colombia.

tourist potential for sun and beach, adventure tourism, aqua tourism, religious tourism, nature tourism, ecotourism, gastronomic tourism, cultural tourism, and agrotourism [53]. The TSC in Sucre can be defined as the interaction of public and private entities represented as first-tier suppliers (lodging, transportation, food, tourism activities) and second-tier suppliers, tourism intermediaries, and tourists. In contrast to the traditional TSC, there are several small and medium-sized tourism providers with a high informality index.

4.2.1. First-Tier Suppliers. In the Department of Sucre, in the second quarter of 2020, there were 514 hotels with the availability of 7022 rooms and 16636 beds with an average occupancy rate of 56.96%. However, in May 2020, occupancy dropped to 7.9% [54]. There are 67 passenger ground transportation companies and one airport. The inventory of tourist attractions of the tourist route of the Golfo de Morrosquillo and Sabana contains 200 georeferenced POIs (42 in Corozal, 16 in Coveñas, 6 in Palmito, 12 in Sampués, 28 in San Marcos, 19 in San Onofre, 23 in Santiago de Tolú, and 54 in Sincelejo) classified as cultural (77%) and natural heritage (23%) [53]. 71.5% of the POIs correspond to architectural infrastructure for the culture that is part of cultural tourism. 13.5% of the POIs correspond to coastal coasts and insular lands ideal for sun and beach tourism. 5.5% corresponds to religious architecture ideal for religious tourism. The water bodies used for aqua tourism represent 5% of the POIs. Finally, 4.5% corresponds to protected natural areas, mountains, karst formations, and fauna and flora observation sites, which fit into the development of nature, adventure, and ecotourism tourism activities. The matrix of POIs and their classification adapted for this study is available upon request to the corresponding author.

4.2.2. Second-Tier Suppliers. At this echelon, there are companies that supply drinking water, solid waste collection, electricity, food, handicraft products, and souvenirs. In Sucre, different gastronomic tourism products are produced informally. These products are also part of the inventory of local products [53]. There are also informal actors dedicated to the production of handicrafts. However, some projects aim to organize this sector as a potential tourist attraction by creating associations and craft routes.

4.2.3. Tour Operators and Travel Agents. There are 639 active national tourism service providers. However, there are 51 travel agencies located in Coveñas, San Marcos, Sincé, Sincelejo, and Tolú, and 14 tour operators located in Tolú, Coveñas, and San Onofre, registered in 2021 in the local Chamber of Commerce [55].

4.3. Building Sucre's Tourism Data Sets. With the information on tourism in Sucre, 16 instances (i.e., input databases for optimization models) are developed (Table 2). The data consider the type of tourism, time windows, budgets, and POI scores. Time windows are calculated based on the opening and closing times of each site (due to the particularity of the beaches, a schedule of 8 : 00 a.m. to 6 : 00 p.m. was provided). The qualification of the POIs presents scores between 0 and 100 based on the items of quality and significance of the criteria of tangible heritage, intangible heritage, groups of special interest, and criteria of natural sites according to the document "methodology for the elaboration of the inventory of tourist attractions" of the Ministerio de Comercio, Industria *y* Turismo [56].

5. Experiments

The model was coded in GAMS software and solved with the CPLEX solver on a computer with 20 GB of RAM, an Intel Core i7-8565U CPU@ 1.8 GHz, a 1 TB hard drive, and a 64-bit operating system. Due to the NP-hard nature of the model, small and medium-sized instances from the literature are used initially. The instances present a total of 21 and 51 nodes.

According to the decision-makers criteria, the tolerance level applied in instances has a value of 20%, $\varphi = 1$, and the α values are 0.2, 0.6, 0.8, and 1. The τ values are the same for all three constraints. In the same way, a variation in the γ and β parameters of the objectives are applied. This variation for the tests corresponds to $\gamma = 0$, 0.2, 0.4, 0.6, 0.8, and 1. $\beta = 1$, 0.8, 0.6, 0.4, 0.2, and 0. Two transport modes (car and bus) are considered. Emissions for each mode are 0.18014 kgCO_2/km and 0.10391 kgCO_2e/passenger-km, respectively [57]. Emission costs are €0.02241 [58]. Finally, $K = 3$. The solutions are shown in Table 3. Subsequently, the model is applied to solve an instance of the case study Toptw-jClassa with 11 nodes (POIs) and Toptw-jMunf with 20 POIs. Actual data is available upon request to the corresponding author. The maximum travel time for tourists in the Toptw-jClassa instance is $T\max = 600$ minutes, and the monetary budget is $P =$ \$COP 40000. For the Toptw-jMunf instance, the values

Table 2: Instances.

Instances	Quantity	Types	Number of POIs	Transport modes
Toptw-jClass	5	a = aquaturism; b = adventure, nature, or ecotourism; c = cultural; d = religious; e = sun and beach	a = 11; b = 10; c = 144; d = 12; e = 27	a, b, c, d, e, and f = 2
Toptw-jSubR	2	a = Golfo; b = Sabanas	a = 65; b = 137	a and b = 2
Toptw-jMun	8	a = Corozal; b = Coveñas; c = Palmito; d = Sampués; e = San Marcos; f = San Onofre; g = Santiago de Tolú; h = Sincelejo	a = 44; b = 18; c = 7; d = 14; e = 29: f = 20; g = 24; h = 59	a, b, c, d, e, f, g, and h = 2
Toptw-jGen	1		200	

Table 3: Numerical results for hptoptw-j21a and 50_c101 instances.

γ	β	α	Hptoptw-j21a				50_c101			
			$Z1$	$Z2$	Time (minutes)	Gap	$Z1$	$Z2$	Time (minutes)	Gap
0	1	0.2	20	80.59	4.3	0%	50	104.03	0.15	0%
		0.6	20	80.59	4.3	0%	50	104.03	0.14	0%
		0.8	20	80.59	4.4	0%	50	104.03	0.14	0%
		1	20	80.59	4.4	0%	50	104.03	0.15	0%
0.2	0.8	0.2	50	86.85	4.3	0%	90	113.5	0.14	0%
		0.6	50	86.85	4.5	0%	90	113.5	0.15	0%
		0.8	50	86.85	5.9	0%	90	113.5	0.15	0%
		1	50	86.85	4.4	0%	90	113.5	0.15	0%
0.4	0.6	0.2	150	114.94	6.1	0%	450	259.1	0.17	0%
		0.6	150	114.94	6.1	0%	450	259.1	0.16	0%
		0.8	150	114.94	6	0%	450	259.1	0.17	0%
		1	140	111.73	4.4	0%	450	259.1	0.23	0%
0.6	0.4	0.2	160	122	5.8	0%	660	429.59	0.25	0%
		0.6	150	114.94	6.6	0%	640	427.50	0.19	0%
		0.8	150	114.94	6.3	0%	640	427.50	0.2	0%
		1	140	111.73	4.5	0%	620	417.38	0.23	0%
0.8	0.2	0.2	340	545.83	6.1	0%	690	526.07	16.82	3.48%
		0.6	340	593.58	7	0%	670	524.94	0.62	0%
		0.8	330	586.51	6.5	0%	660	486.25	0.21	0%
		1	330	615.16	4.7	0%	630	456.07	2.45	0%
1	0	0.2	350	770.82	6.6	0%	610	3002.8	16.84	32.78%
		0.6	350	702.79	6.2	0%	660	1844.1	16.83	14,86
		0.8	340	677.63	7.1	0%	660	1844.1	16.85	14.77%
		1	330	696.93	4.4	0%	670	1455.08	16.8	5.94%

Table 4: Numerical results for real instances Toptw-jClassa and Toptw-jMunf.

γ	β	α	Toptw-jClassa				Toptw-jMunf			
			$Z1$	$Z2$	Time (minutes)	Gap (%)	$Z1$	$Z2$	Time (minutes)	Gap (%)
0	1	0.2	223	525.9	0.1	0	195	605.64	0.11	0
		0.6	223	761.53	0.1	0	195	605.64	0.1	0
		0.8	223	761.53	0.1	0	195	605.64	0.1	0
		1	223	761.53	0.1	0	195	605.64	0.12	0
0.2	0.8	0.2	223	525.9	0.1	0	483	659.33	16.89	14.9
		0.6	223	761.53	0.1	0	478	659.34	16.79	15
		0.8	223	761.53	0.1	0	478	659.4	16.84	14.42
		1	223	761.53	0.1	0	478	659.34	16.9	13.67
0.4	0.6	0.2	223	525.9	0.1	0	940	817.9	16.79	90.45
		0.6	223	761.53	0.1	0	879	814.95	16.81	75.26
		0.8	223	761.53	0.1	0	874	813.09	16.73	69.77
		1	223	761.53	0.1	0	874	813.13	16.85	62.01
0.6	0.4	0.2	223	525.9	0.1	0	1016	898.25	16.9	33.46
		0.6	360	953.6	0.2	0	955	893.53	16.82	40.45
		0.8	223	761.53	0.1	0	950	891.67	16.9	35.5
		1	223	761.53	0.1	0	950	891.67	16.82	26.08

Table 4: Continued.

γ	β	α	Toptw-jClassa $Z1$	$Z2$	Time (minutes)	Gap (%)	Toptw-jMunf $Z1$	$Z2$	Time (minutes)	Gap (%)
0.8	0.2	0.2	428	998.56	0.475	0	1038	945.81	16.5	10.24
		0.6	360	953.6	0.28	0	968	940.35	16.76	13.01
		0.8	428	1479.82	0.99	0	968	940.36	16.8	9.37
		1	428	1479.82	0.47	0	950	891.67	16.79	5.48
1	0	0.2	710	3651.86	0.1	0	1044	1142.49	16.86	4.8
		0.6	710	3790.42	0.1	0	968	944.37	16.75	7.08
		0.8	710	3803.89	0.2	0	968	940.39	16.8	4.74
		1	649	3647.64	10	0	950	1209.42	16.85	2.66

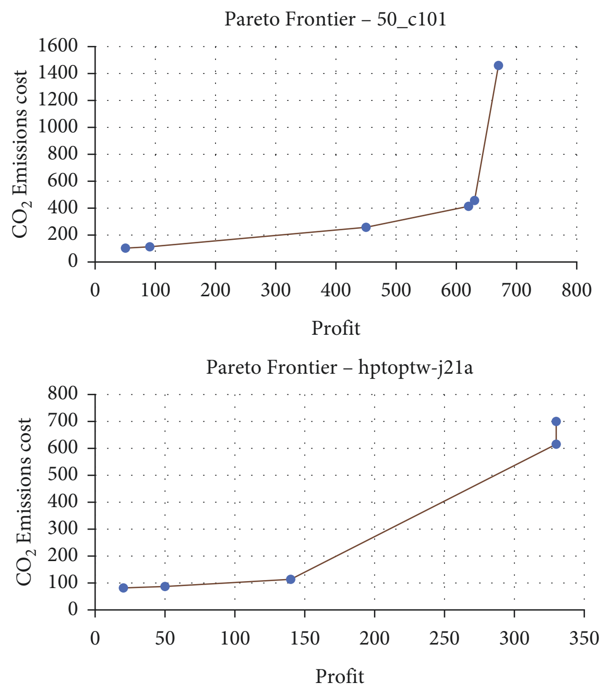

Figure 2: Pareto frontier.

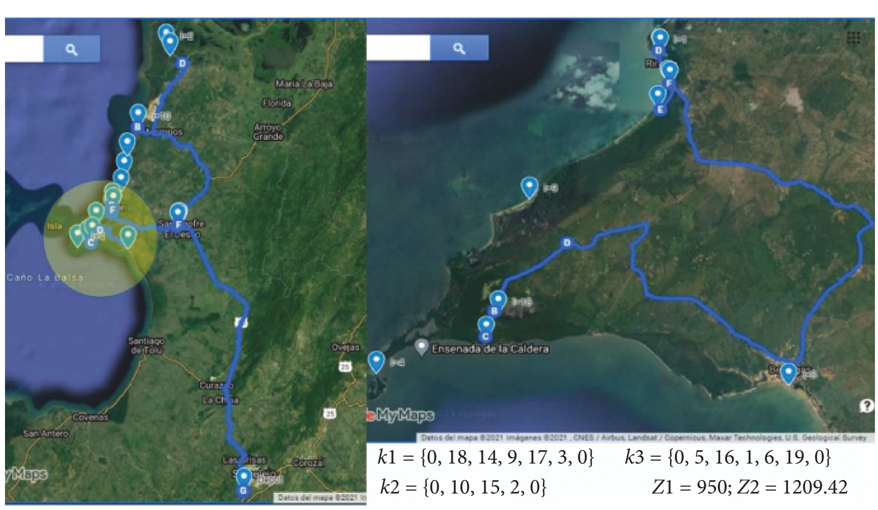

Figure 3: Example itinerary for Toptw-jMunf instance.

are $T\max = 550$ minutes and $P = \$\text{COP}\ 100000$. The solutions are shown in Table 4.

The increase in the number of nodes results in some solutions for instance 50_c101 not reaching a gap of 0% with $\gamma = 1$ and $\beta = 0$. However, decreasing the weight of γ results in optimal solutions with a gap of 0%. In both instances, hptoptw-j21a and 50_c101, variations of α-cuts generate different solutions from the weights $\gamma = 0.6$ and $\beta = 0.4$ up to $\gamma = 1$ and $\beta = 0$. The α-cuts vary the solutions in both objectives $Z1$ (Profit expressed in COP$) and $Z2$ (cost of emissions). The results of the combinations of the weights of γ, β, and $\alpha = 1$ allow the Pareto frontier to be constructed (Figure 2). The results show a directly proportional relationship between the objectives (i.e., as the tourist's profit increases, CO_2 emissions increase).

For Toptw-jClassa instance, the results obtained with $\gamma = 0–0.6$ and $\beta = 1–0.4$ are the same for both objectives in the α-cuts. However, by increasing the value of γ (0.8 to 1) and applying the α-cut, variations in the results are generated mainly for z_2. The results of the Toptw-jMunf instance demonstrate the complexity of the model and the real data. In most solutions, a gap of 0% is not reached. We observe that the model stops at approximately 16.5 minutes when the 0% gap is not reached. For this reason, we tested by setting the run time to 4 hours to observe the result and force the model to run for a longer time. The results show that despite increasing time, the solutions are similar.

Overall, the results constitute the optimal solutions set and demonstrate results consistent with the fuzzy approach. An example of the path generated for Toptw-jMunf $\gamma = 1$, $\beta = 0$, and $\alpha = 1$ is shown in Figure 3.

6. Concluding Remark

Tourism as an economic activity is becoming more relevant in the development of many regions. The negative impact of the COVID-19 crisis is a turning point to reinvent and rethink the models and processes of many activities. Adapting to dynamics of greater complexity, dynamism, and flexibility, along with sensitivity and environmental protection, have become essential. Tourist destinations for the management of the same, and as a service to the organization and planning of trips by tourists, must incorporate tools for the design of tourist itineraries that take this context into account. This work characterizes the tourism supply chain in the Sucre region and builds a set of data that will improve decision-making. A formulation of a Multimodal Team Orientation Problem and Biobjective Fuzzy Constraints with Time Windows is also proposed to model a variant of the tourist trip design problem. The model maximizes profit and minimizes CO_2 emission costs. Flexible and imprecise constraints are associated with time windows, maximum travel time, and budget and are modeled as fuzzy constraints. The proposed objectives with sustainability criteria provide solutions that respond to environmentally friendly itineraries. To find solutions with this model, we use a fuzzy optimization approach. In a simple way, this methodology facilitates the search for solutions by transforming the fuzzy model into an equivalent crisp auxiliary model. To find solutions with this model, we use a fuzzy optimization approach. In a simple way, this methodology facilitates the search for solutions by transforming the fuzzy model into an equivalent crisp auxiliary model. A set of tests are performed using instances from the literature and real instances obtained from the northern region of Colombia. The results determine that the proposed model finds adequate solutions to the problem. The multiobjective fuzzy approach applied is consistent, and the solution sets obtained are coherent with both the objectives and the flexible and imprecise nature of the modeled constraints. Although the approach used is valid, it is observed that the optimal solutions obtained with the use of CPLEX are not reached with larger instances in a reasonable time. This situation determines the need to implement approximate techniques, more specifically metaheuristics. Future research may apply metaheuristics or hybrid procedures to find approximate solutions and improve computational efficiency. In addition, the construction of itineraries demands routes for tourist groups (that is, tourists travel in groups of family and friends, among others). Therefore, another line of future research is to develop models that build itineraries for groups of tourists.

Data Availability

No data were used to support this study.

Conflicts of Interest

The author declares that they have no conflicts of interest

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