UNIVERSIDAD NACIONAL DE COLOMBIA
SEDE MEDELLÍN
FACULTAD DE MINAS

DYNA
http://dyna.medellin.unal.edu.co/

Delineation of special economic zones using integer linear programming

Nestor M. Cid-Garcia[a], Nohemi Alvarez-Jarquin[a], Loecelia Ruvalcaba[a] & Gabriel Correa-Medina[b]

[a] *CONACYT - Centro de Investigación en Ciencias de Información Geoespacial, Aguascalientes, Mexico. ncid@centrogeo.edu.mx, nalvarez@centrogeo.edu.mx, lruvalcaba@centrogeo.edu.mx*
[b] *Centro de Investigación en Ciencias de Información Geoespacial, Aguascalientes, Mexico. gcorrea@centrogeo.edu.mx*

Received: September 13th, 2018. Received in revised form: March 1st, 2019. Accepted: March 22th, 2019.

Abstract
Special Economic Zones (SEZs) are delimited geographic areas located within the borders of a country with the objective of stimulating the local economy of a specific region. SEZs have multiple labor and fiscal benefits that allow them to enhance the economic level of the region through the generation of quality jobs, export growth, government investment, and technology transfer, just to name a few. China and other countries have demonstrated the benefits of SEZs and their economic impact on the local region. This article proposes a method based on Integer Linear Programming to delineate SEZs in a way that takes into account the population of the region, the distance and travel time between municipalities, the infrastructure of the region, and the Federal Laws imposed by the government. Experimental results based on real instances concerning the Isthmus of Tehuantepec, México, validate the method and enable a graphical visualization of the solution.

Keywords: special economic zones; integer linear programming; mathematical modeling.

Delimitación de zonas económicas especiales utilizando programación lineal entera

Resumen
Las Zonas Económicas Especiales (ZEEs) son áreas geográficas delimitadas ubicadas dentro de las fronteras de un país con el objetivo de impulsar la economía local de una región específica. Las ZEEs tienen múltiples beneficios laborales y fiscales que les permiten mejorar el nivel económico de la región a través de la generación de empleos de calidad, crecimiento de las exportaciones, inversión gubernamental y transferencia de tecnología, solo por nombrar algunos. China y otros países han demostrado los beneficios de las Zonas Económicas Especiales y su impacto económico para la región local. El objetivo de este artículo es proponer una metodología basada en Programación Lineal Entera para generar ZEE tomando en consideración la población de la región, la distancia y el tiempo de viaje entre los municipios, la infraestructura de la región y las Leyes Federales impuestas por los gobiernos. Los resultados experimentales basados en instancias reales del Istmo de Tehuantepec, México, validan el método y permiten una visualización gráfica de la solución.

Palabras clave: zonas económicas especiales; programación lineal entera; modelación matemática.

1. Introduction

Special Economic Zones (SEZs) are delimited geographic areas contained within a country's national boundaries, with natural and logistical advantages suitable for high productivity. SEZs provide an exceptional business environment to attract investment, develop international trade, generate quality jobs, as well as offering fiscal and labor benefits, a world-class infrastructure and support programs (human capital, financing, and innovation). SEZs promote the economic activity within the zone and the industrial zones that focus mainly on specific economic activities [1].

The World Bank considers that the concept of an SEZ includes a wide variety of types of economic zone. Among the most important are *Free Trade Zones* (FTZs) which re-

How to cite: Cid-Garcia, N.M., Alvarez-Jarquin, N., Ruvalcaba, L. and Correa-Medina, G., Delineation of special economic zones using integer linear programming. DYNA, 86(209), pp. 141-150, April - June, 2019.

© The author; licensee Universidad Nacional de Colombia.

export goods enjoying certain customs advantages, and *Export Processing Zones* (EPZs), which promote economic growth by attracting foreign investment and producing exports [2,3].

According to Zeng [4], in the last three decades, China has been an example for other countries in the creation of SEZs, because these have contributed significantly to the generation of employment, exports, gross domestic product and attraction of foreign investment.

In 1980, the first four SEZs of China were created: *Shenzhen*, *Zhuai,* and *Shantou* belong to Guangdong Province and *Xiamen* belongs to Fujian Province. These two provinces are strategically located in coastal areas close to Hong Kong, Macao, and Taiwan. Of all these zones, Shenzhen is the most developed, probably because of its location at the delta of the Pearl River and immediately north of Hong Kong where capitalist modes of economic growth and management have flourished [5]. Several studies are still assessing the great economic achievement of this region, in order to replicate it [6].

The success of SEZs inside China has inspired other countries, such as Honduras, Taiwan, South Korea, Madagascar, India, El Salvador and Bangladesh, to create their own. This has provided multiple benefits, such as employment generation, export growth and diversification, government revenue and technology transfer [1,7-10]. For instance, India is one of the many countries where, thanks to the establishment of SEZs, the jewelry and electronics industry has grown rapidly and this has contributed to creating quality jobs [11,12]. Through a three-sector Harris-Todaro type model it has been established that agriculture and SEZs can grow at the same time if the government provides support for projects that benefit and boost land efficiency [13].

The main contribution of this paper is to propose a tool for delineating SEZs based on mathematical modeling. Our method is applied in a case study of the Isthmus of Tehuantepec, Mexico.

2. SEZs and mathematical modeling

For a decision maker, designing an SEZ is not an easy task, mainly due to two reasons: defining the spatial unit to use (province, state, town, etc.), and determining its area of influence. Mathematical tools, in particular, Integer Linear Programming (ILP), have been used to solve several complex real-life problems where the decision maker does not find it easy to make a decision.

The problem of the delineation of SEZs is similar to the territory design problem (TDP), where small geographic basic units (municipalities) are grouped into larger geographic clusters called territories (economic zones), which are acceptable or optimal according to the relevant planning criteria [14]. The TDP has several applications in political districting [15-20], sales territory design [14,21-23], agricultural zones [24,25] and public services [26]. Some surveys of the methods and algorithms used in the TDP can be found in [27-29] for districting problems; in [26] for sales districting and; in [30] for political districting.

The originality of the present paper lies in the way to treat the delineation of SEZs. To the best of our knowledge, there are no studies using an Integer Linear Programming approach to delimiting these zones and their areas of influence. In this article, we propose two mathematical formulations to delineate SEZs and their areas of influence. The first one is based on the assignment problem and, the second one on the facility location problem.

3. Methodology

Some specific characteristics that have been of great importance when creating an SEZ are a) the internal characteristics of the zone, b) its relative location and, c) its interactions with areas of intense commercial activity [4]. Taking into account these characteristics we propose a new method to delineate SEZs by using ILP. We present two mathematical formulations. In the first one, we consider the time and distance between the municipalities, their population, any extreme poverty, and the infrastructure of the region. A particularity of this model is that some municipalities are fixed previously as the center of each economic zone. In the second model, the same considerations are taken, but the center of each SEZ is optimally chosen by the model considering a set of potential sites, given previously, where the center of each SEZ can be determined.

3.1. Model A

In this model, the minimum number of SEZs is previously computed according to the population density and the restrictions on population imposed by the government. Then, the center for each SEZ is established a priori considering the potential of each municipality. Finally, the model selects the best way of assigning municipalities to an SEZ.

To formalize this problem, let I be the set of municipalities where $I=\{1,\dots,m\}$, and let J be the set of SEZs where $J=\{1,\dots,n\}$ computed by Eq. (1), where; p_i is the population of municipality i, and UP is the maximum population allowed in an SEZ. Therefore, the minimum number of zones is initially given by the following equation:

$$n = \left\lceil \frac{\sum_{i\in I} p_i}{UP} \right\rceil. \quad (1)$$

The objective is to minimize the distance Dij from a municipality i to an SEZ j. The model must satisfy the bounds of minimum and maximum population (LP and UP, respectively) previously established. The decision variables for this formulation are:

$$x_{ij} = \begin{cases} 1 & \text{if municipality } i \text{ is assigned to SEZ } j, \text{ and} \\ 0 & \text{otherwise.} \end{cases}$$

The resulting mathematical model is:

$$\min\ z = \sum_{i\in I}\sum_{j\in J} D_{ij}\, x_{ij} \quad (2)$$

subject to:

$$\sum_{j\in J} x_{ij} = 1, \qquad \forall i \in I \tag{3}$$

$$\sum_{i\in I} p_i x_{ij} \geq LP, \qquad \forall j \in J \tag{4}$$

$$\sum_{i\in I} p_i x_{ij} \leq UP, \qquad \forall j \in J \tag{5}$$

$$x_{ij} \in \{0,1\}, \qquad \forall i \in I, \forall j \in J \tag{6}$$

The objective function is represented by (2), where the total distance between municipalities and SEZs is minimized. Constraints (3) ensure that each municipality is assigned to only one economic zone. Constraints (4) and (5) ensure that the population for each economic zone must satisfy the local specifications. Finally, in (6) the nature of the variables is declared.

Version 2 of this formulation minimizes the time instead of the distance. Replacing the objective function (2) we have

$$\min \ z = \sum_{i\in I}\sum_{j\in J} T_{ij}\, x_{ij} \tag{7}$$

where T_{ij} is the travel time from municipality i to potential SEZ j.

An important reason to consider the travel time instead of the distance is that often the available infrastructure, official speed limits, historical traffic speed data, and others, have shown that the distance and travel time are not proportional; in some cases, the travel time can be bigger in shorter distances than in larger distances. Therefore, it is very important to consider the time.

3.2. Model B

This model is based on the facility location problem, which has practical importance in problems where the objective is to choose the location of facilities, such as industrial plants or warehouses, in order to minimize the costs or maximize the profit of satisfying the demand for some commodity (see [31]).

For this model the same parameters are considered as in model A. However, in this case, the selection of each center of an SEZ is chosen by the model instead of being fixed previously. To formalize this, we consider a set of municipalities $I=\{1,\ldots,m\}$ each one with a specific population p_i, and a set of potential sites $J=\{1,\ldots,ZONES\}$ where the center of the economic zone can be established. In this case, the potential municipalities in the region define the number of zones, denoted by *ZONES,* which differs from model A to model B. The distance from municipality i to potential site j is denoted by D_{ij}. The variables for the integer linear programming formulation are:

$$y_j = \begin{cases} 1 & \text{if site } j \text{ is established as the center of an SEZ, and} \\ 0 & \text{otherwise.} \end{cases}$$

$$w_{ij} = \begin{cases} 1 & \text{if municipality } i \text{ is assigned to SEZ } j\text{, and} \\ 0 & \text{otherwise.} \end{cases}$$

The mathematical formulation is:

$$\min \ z = \sum_{i\in I}\sum_{j\in J} D_{ij}\, w_{ij} \tag{8}$$

subject to:

$$\sum_{j\in J} w_{ij} = 1, \qquad \forall i \in I \tag{9}$$

$$\sum_{i\in I} p_i w_{ij} \geq LP\, y_j, \qquad \forall j \in J \tag{10}$$

$$\sum_{i\in I} p_i w_{ij} \geq LP\, y_j, \qquad \forall j \in J \tag{11}$$

$$w_{ij} \leq y_j, \qquad \forall i \in I, \forall j \in J \tag{12}$$

$$\sum_{j\in J} y_j = n, \tag{13}$$

$$w_{ij} \in \{0,1\}, \qquad \forall i \in I, \forall j \in J \tag{14}$$

$$y_j \in \{0,1\}. \qquad \forall j \in J \tag{15}$$

In the objective function (8) the aim is to minimize the total distance between the municipalities and the SEZs. Constraints (9) ensure that each municipality is assigned to only one economic zone, which means a municipality cannot be in two economic zones simultaneously. Constraints (10) and (11) ensure that the population for each SEZ must be satisfactory if it is selected. Constraints (12) ensure that a municipality is going to be assigned to a special economic zone only if it is selected. Constraint (13) limits the number of special economic zones with the minimum number required according to Eq. (1). Finally, in (14) and (15) the nature of the variables is declared.

As in model A, version 2 of this formulation consists in considering the *time* instead of *distance* as in (8), and then we have:

$$\min \ z = \sum_{i\in I}\sum_{j\in J} T_{ij}\, w_{ij} \tag{16}$$

3.3. Case study: Special Economic Zones in Mexico

The area of interest for the creation of these SEZs is located in the region of the Isthmus of Tehuantepec in Mexico that includes three states: Veracruz, Oaxaca, and Chiapas (see Fig. 1). This area is considered as a way of transisthmian communication between the Atlantic Ocean and the Pacific Oceans, which impacts on the transportation of goods destined for national and international markets.

Table 1.
Population for each municipality of the Isthmus of Tehuantepec, Mexico.

ID	Municipality	Pop.	ID	Municipality	Pop.
1	Coatzacoalcos	319187	31	Santo Domingo Tehuantepec	64639
2	Cosoleacaque	129527	32	Santa Maria Mixtequilla	4555
3	Oteapan	16222	33	Magdalena Tlacotepec	1220
4	Zaragoza	11354	34	Santiago Laollaga	3326
5	Jaltipan	41644	35	Santo Domingo Chihuitan	1486
6	Texistepec	20887	36	San Pedro Comitancillo	4234
7	Oluta	16710	37	San Pedro Huilotepec	3146
8	Sayula de Aleman	32721	38	Salina Cruz	89211
9	San Juan Evangelista	33929	39	San Blas Atempa	18406
10	Jesus Carranza	29413	40	Santa Maria Petapa	16518
11	Hidalgotitlan	19587	41	El Barrio de la Soledad	14277
12	Uxpanapa	29434	42	Ciudad Ixtepec	28637
13	Nanchital de Lazaro Cardenas del Rio	30039	43	Asuncion Ixtaltepec	15105
14	Ixhuatlan del Sureste	15800	44	El Espinal	8575
15	Moloacan	17504	45	Santa Maria Xadani	8795
16	Agua Dulce	48091	46	Heroica Ciudad de Juchitan de Zaragoza	98043
17	Minatitlan	157393	47	San Mateo del Mar	14835
18	Las Choapas	81827	48	San Dionisio del Mar	5127
19	Matias Romero Avendaño	39828	49	Union Hidalgo	15347
20	San Juan Guichicovi	29364	50	Santo Domingo Ingenio	7965
21	Santo Domingo Petapa	9157	51	San Miguel Chimalapa	6817
22	Santa Maria Guienagati	3168	52	Santa Maria Chimalapa	9078
23	Guevea de Humboldt	5409	53	Santiago Niltepec	5327
24	Santiago Lachiguiri	4886	54	San Francisco Ixhuatan	8980
25	Santa Maria Totolapilla	839	55	San Francisco del Mar	7650
26	Santa Maria Jalapa del Marques	13148	56	Reforma de Pineda	2723
27	Magdalena Tequisistlan	6038	57	Santo Domingo Zanatepec	12161
28	San Pedro Huamelula	10014	58	San Pedro Tapanatepec	15152
29	Santiago Astata	3708	59	Chahuites	11413
30	San Miguel Tenango	729			

Source: The Authors.
Data obtained from the Mexican National Institute of Statistics and Geography (INEGI).

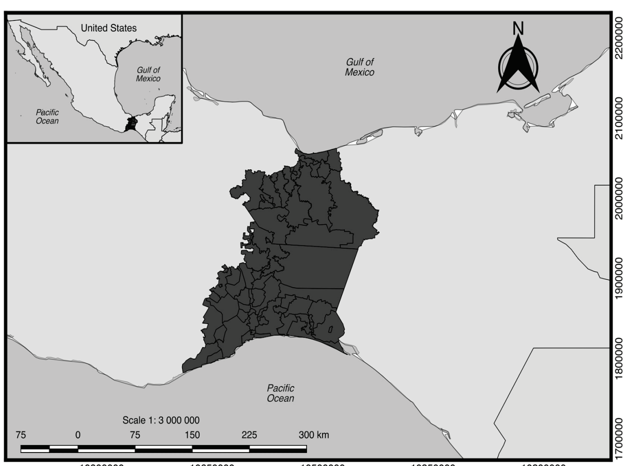

Figure 1. The Isthmus of Tehuantepec, Mexico (black zone).
Source: The Authors.

Table 2.
Infrastructure for municipalities that can be the center of an SEZ.

ID	Municipality	H	T	A	P	R	T
1	Coatzacoalcos	1	1	0	1	0	3
2	Cosoleacaque	1	1	0	0	0	2
5	Jaltipan	1	1	0	0	0	2
6	Texistepec	1	1	0	0	0	2
7	Oluta	1	1	0	0	0	2
8	Sayula de Aleman	1	1	0	0	0	2
9	San Juan Evangelista	1	1	0	0	0	2
10	Jesus Carranza	1	1	0	0	0	2
17	Minatitlan	1	0	1	0	1	3
19	Matias Romero Avedaño	1	1	0	0	0	2
20	San Juan Guichicovi	1	1	0	0	0	2
31	Santo Domingo Tehuantepec	1	1	0	0	0	2
38	Salina Cruz	1	1	0	1	1	4
40	Santa Maria Petapa	1	1	0	0	0	2
42	Ciudad Ixtepec	1	1	0	0	0	2
43	Asuncion Ixtaltepec	1	1	1	0	0	3
46	H. Ciudad de Juchitan de Zaragoza	1	1	0	0	0	2
49	Union Hidalgo	1	1	0	0	0	2
58	San Pedro Tapanatepec	1	1	0	0	0	2

Source: The Authors.

Table 1 shows the municipalities of each state that will be considered when creating the SEZs. The first eighteen municipalities belong to the state of Veracruz and the rest belong to the state of Oaxaca. The first and fourth columns show the ID, the second and fifth columns show the names, and the third and sixth columns show the population for each municipality.

According to the Mexican Federal Law for the creation of SEZs, these will be established with the aim of boosting through investments the economic growth of the country's regions. They must meet the following requirements:

a) They must be located among the ten states with the highest incidence of extreme poverty.
b) These zones should be established in geographic areas that have a strategic hub with access to large

infrastructures such as airports, railways, ports and inter-oceanic highways in order to increase productivity.

c) Each SEZ can be integrated with at least one municipality. Each zone must have a population between 50000 and 500000 inhabitants.

Oaxaca has the second highest incidence of extreme poverty of the states of Mexico, while Veracruz is in sixth place; therefore, the first requirement mentioned above is fulfilled. The objective of creating SEZs in these two states is to exploit their strategic location.

Table 2 shows the infrastructure of the potential municipalities that are candidates to be the center of an SEZ. The first and second columns indicatae the municipality; the third to seventh columns show the available infrastructure (a ‘1’ means the municipality has a highway (H), train (T), airport (A), port (P) or refinery (R)). The last column shows the total number of elements (T).

4. Results

Experimental results based on real data of the Isthmus of Tehuantepec, México, validate the method and enable a graphical visualization of the solution. In this section, the integer programming formulations for the SEZ problem are validated. The mathematical models were solved using CPLEX version 12.7.0.1 executed on a workstation equipped with 64 GB of RAM and 8 Intel(R) Xeon(R) E5-2609 v4 Processors @ 1.7 GHz.

4.1. Model A

For this model, we first compute the minimum number of SEZs required for partitioning the region of the isthmus using Eq. (1). In this case, the minimum number of zones was equal to 4.

Table 3.
Experimental results for version 1 of model A. Part I.

ID	J1	J2	J3	J4	Distance	Travel Time	Solver Time	ID	J1	J2	J3	J4	Distance	Travel Time	Solver Time
1	1	38	2	5	4629.00	4586.00	0.02	35	1	38	6	10	4277.10	4376.00	0.14
2	1	38	2	6	4517.30	4524.00	0.37	36	1	38	6	17	4573.30	4554.00	0.04
3	1	38	2	7	4484.20	4415.00	0.04	37	1	38	6	19	3495.10	3897.00	0.18
4	1	38	2	8	4452.50	4366.00	0.16	38	1	38	6	20	3886.50	4363.00	0.13
5	1	38	2	9	4481.60	4463.00	0.12	39	1	38	6	31	3845.10	3869.00	0.18
6	1	38	2	10	4153.70	4301.00	0.04	40	1	38	6	40	3539.40	4031.00	0.03
7	1	38	2	17	4719.10	4587.00	0.17	41	1	38	6	42	3200.90	3570.00	0.14
8	1	38	2	19	3399.30	3831.00	0.03	42	1	38	6	43	3219.50	3819.00	0.21
9	1	38	2	20	3790.70	4297.00	0.26	43	1	38	6	46	3159.90	3745.00	0.08
10	1	38	2	31	3749.30	3803.00	0.08	44	1	38	6	49	3203.10	3672.00	0.09
11	1	38	2	40	3443.60	3965.00	0.32	45	1	38	6	58	3882.70	4082.00	0.08
12	1	38	2	42	3105.10	3504.00	0.10	46	1	38	7	8	4704.20	4535.00	0.05
13	1	38	2	43	3123.70	3753.00	0.02	47	1	38	7	9	4704.90	4583.00	0.38
14	1	38	2	46	3064.10	3679.00	0.23	48	1	38	7	10	4291.60	4339.00	0.04
15	1	38	2	49	3107.30	3606.00	0.03	49	1	38	7	17	4550.00	4449.00	0.05
16	1	38	2	58	3793.50	4007.00	0.26	50	1	38	7	19	3509.60	3860.00	0.02
17	1	38	5	6	4600.00	4570.00	0.02	51	1	38	7	20	3901.00	4326.00	0.03
18	1	38	5	7	4592.10	4470.00	0.08	52	1	38	7	31	3859.60	3832.00	0.05
19	1	38	5	8	4553.80	4420.00	0.12	53	1	38	7	40	3553.90	3994.00	0.17
20	1	38	5	9	4572.40	4496.00	0.09	54	1	38	7	42	3215.40	3533.00	0.09
21	1	38	5	10	4165.30	4273.00	0.04	55	1	38	7	43	3234.00	3782.00	0.05
22	1	38	5	17	4675.40	4576.00	0.29	56	1	38	7	46	3174.40	3708.00	0.16
23	1	38	5	19	3383.30	3794.00	0.02	57	1	38	7	49	3217.60	3635.00	0.09
24	1	38	5	20	3774.70	4260.00	0.01	58	1	38	7	58	3886.50	4012.00	0.32
25	1	38	5	31	3733.30	3766.00	0.08	59	1	38	8	9	4744.70	4601.00	0.04
26	1	38	5	40	3427.60	3928.00	0.01	60	1	38	8	10	4324.60	4342.00	0.04
27	1	38	5	42	3089.10	3467.00	0.03	61	1	38	8	17	4518.30	4400.00	0.08
28	1	38	5	43	3107.70	3716.00	0.34	62	1	38	8	19	3542.60	3863.00	0.26
29	1	38	5	46	3048.10	3642.00	0.02	63	1	38	8	20	3934.00	4329.00	0.13
30	1	38	5	49	3091.30	3569.00	0.10	64	1	38	8	31	3892.60	3835.00	0.15
31	1	38	5	58	3777.50	3970.00	0.32	65	1	38	8	40	3586.90	3997.00	0.14
32	1	38	6	7	4680.30	4591.00	0.08	66	1	38	8	42	3248.40	3536.00	0.10
33	1	38	6	8	4627.10	4522.00	0.10	67	1	38	8	43	3267.00	3785.00	0.13
34	1	38	6	9	4654.00	4622.00	0.08	68	1	38	8	46	3207.40	3711.00	0.22

Source: The Authors.

Table 4.
Experimental results for version 1 of model A. Part II.

ID	J1	J2	J3	J4	Distance	Travel Time	Solver Time	ID	J1	J2	J3	J4	Distance	Travel Time	Solver Time
69	1	38	8	49	3250.60	3638.00	0.14	103	1	38	19	40	4429.90	4813.00	0.26
70	1	38	8	58	3912.30	4003.00	0.20	104	1	38	19	42	3814.00	4208.00	0.27
71	1	38	9	10	4445.00	4498.00	0.03	105	1	38	19	43	3812.80	4371.00	0.08
72	1	38	9	17	4557.00	4512.00	0.04	106	1	38	19	46	3812.80	4369.00	0.12
73	1	38	9	19	3663.00	4019.00	0.03	107	1	38	19	49	3827.40	4286.00	0.12
74	1	38	9	20	4054.40	4485.00	0.16	108	1	38	19	58	4069.80	4485.00	0.06
75	1	38	9	31	4013.00	3991.00	0.12	109	1	38	20	31	4328.10	4543.00	0.13
76	1	38	9	40	3707.30	4153.00	0.39	110	1	38	20	40	4367.70	4827.00	0.12

77	1	38	9	42	3368.80	3692.00	0.20	111	1	38	20	42	3853.00	4300.00	0.24
78	1	38	9	43	3387.40	3941.00	0.22	112	1	38	20	43	3855.10	4477.00	0.03
79	1	38	9	46	3327.80	3867.00	0.04	113	1	38	20	46	3845.00	4463.00	0.10
80	1	38	9	49	3371.00	3794.00	0.05	114	1	38	20	49	3864.50	4382.00	0.36
81	1	38	9	58	4039.10	4153.00	0.44	115	1	38	20	58	4189.70	4581.00	0.08
82	1	38	10	17	4216.30	4320.00	0.02	116	1	38	31	40	4303.40	4754.00	0.10
83	1	38	10	19	3972.20	4292.00	0.05	117	1	38	31	42	4543.70	4744.00	0.07
84	1	38	10	20	4363.90	4757.00	0.03	118	1	38	31	43	4566.30	5043.00	0.05
85	1	38	10	31	4131.90	4210.00	0.09	119	1	38	31	46	4507.30	4807.00	0.07
86	1	38	10	40	4004.40	4411.00	0.03	120	1	38	31	49	4400.40	4744.00	0.25
87	1	38	10	42	3597.30	3922.00	0.16	121	1	38	31	58	4833.10	4838.00	0.06
88	1	38	10	43	3604.30	4119.00	0.40	122	1	38	40	42	3935.00	4398.00	0.20
89	1	38	10	46	3576.90	4090.00	0.22	123	1	38	40	43	3934.60	4562.00	0.14
90	1	38	10	49	3596.10	4000.00	0.09	124	1	38	40	46	3934.50	4560.00	0.14
91	1	38	10	58	4034.10	4300.00	0.06	125	1	38	40	49	3948.20	4475.00	0.11
92	1	38	17	19	3437.10	3825.00	0.01	126	1	38	40	58	4180.70	4620.00	0.14
93	1	38	17	20	3828.50	4299.00	0.00	127	1	38	42	43	4539.60	4848.00	0.04
94	1	38	17	31	3787.10	3805.00	0.05	128	1	38	42	46	4328.10	4781.00	0.33
95	1	38	17	40	3481.40	3967.00	0.01	129	1	38	42	49	4218.10	4668.00	0.05
96	1	38	17	42	3142.90	3506.00	0.03	130	1	38	42	58	4292.50	4561.00	0.06
97	1	38	17	43	3161.50	3755.00	0.19	131	1	38	43	46	4383.40	4918.00	0.07
98	1	38	17	46	3101.90	3681.00	0.01	132	1	38	43	49	4253.30	4738.00	0.28
99	1	38	17	49	3145.10	3608.00	0.05	133	1	38	43	58	4331.50	4798.00	0.10
100	1	38	17	58	3831.30	4009.00	0.17	134	1	38	46	49	4323.10	4849.00	0.17
101	1	38	19	20	4358.10	4803.00	0.04	135	1	38	46	58	4332.00	4723.00	0.14
102	1	38	19	31	4176.70	4498.00	0.20	136	1	38	49	58	4470.20	4777.00	0.23

Source: The Authors.

Table 5.
Experimental results for version 2 of model A. Part I.

ID	J1	J2	J3	J4	Distance	Travel Time	Solver Time	ID	J1	J2	J3	J4	Distance	Travel Time	Solver Time
1	1	38	2	5	4646.4	4548.00	0.03	35	1	38	6	10	4308.6	4366.00	0.28
2	1	38	2	6	4634.6	4480.00	0.05	36	1	38	6	17	4642.8	4493.00	0.02
3	1	38	2	7	4587.5	4401.00	0.20	37	1	38	6	19	3512.6	3879.00	0.13
4	1	38	2	8	4529.8	4361.00	0.16	38	1	38	6	20	4006.3	4178.00	0.12
5	1	38	2	9	4592.9	4448.00	0.25	39	1	38	6	31	3845.1	3869.00	0.07
6	1	38	2	10	4215	4255.00	0.20	40	1	38	6	40	3759	4012.00	0.19
7	1	38	2	17	4812.9	4559.00	0.04	41	1	38	6	42	3200.9	3570.00	0.14
8	1	38	2	19	3419	3768.00	0.01	42	1	38	6	43	3234.3	3808.00	0.12
9	1	38	2	20	3912.7	4067.00	0.04	43	1	38	6	46	3192.1	3674.00	0.03
10	1	38	2	31	3751.5	3758.00	0.08	44	1	38	6	49	3203.1	3672.00	0.04
11	1	38	2	40	3665.4	3901.00	0.02	45	1	38	6	58	3924.7	4027.00	0.16
12	1	38	2	42	3107.3	3459.00	0.03	46	1	38	7	8	4707.6	4532.00	0.24
13	1	38	2	43	3140.7	3697.00	0.09	47	1	38	7	9	4738.9	4573.00	0.18
14	1	38	2	46	3098.5	3563.00	0.03	48	1	38	7	10	4325.3	4325.00	0.23
15	1	38	2	49	3109.5	3561.00	0.11	49	1	38	7	17	4595.2	4415.00	0.10
16	1	38	2	58	3868.9	3922.00	0.04	50	1	38	7	19	3529.3	3838.00	0.13
17	1	38	5	6	4673.4	4535.00	0.02	51	1	38	7	20	4023	4137.00	0.16
18	1	38	5	7	4618.1	4461.00	0.15	52	1	38	7	31	3861.8	3828.00	0.16
19	1	38	5	8	4553.9	4420.00	0.18	53	1	38	7	40	3775.7	3971.00	0.03
20	1	38	5	9	4606.4	4486.00	0.20	54	1	38	7	42	3217.6	3529.00	0.06
21	1	38	5	10	4196.8	4263.00	0.30	55	1	38	7	43	3251	3767.00	0.17
22	1	38	5	17	4713.1	4513.00	0.09	56	1	38	7	46	3208.8	3633.00	0.06
23	1	38	5	19	3400.8	3776.00	0.05	57	1	38	7	49	3219.8	3631.00	0.05
24	1	38	5	20	3894.5	4075.00	0.11	58	1	38	7	58	3911.2	3975.00	0.09
25	1	38	5	31	3733.3	3766.00	0.08	59	1	38	8	9	4760.9	4579.00	0.43
26	1	38	5	40	3647.2	3909.00	0.02	60	1	38	8	10	4356.1	4332.00	0.10
27	1	38	5	42	3089.1	3467.00	0.05	61	1	38	8	17	4537.5	4375.00	0.10
28	1	38	5	43	3122.5	3705.00	0.08	62	1	38	8	19	3560.1	3845.00	0.04
29	1	38	5	46	3080.3	3571.00	0.08	63	1	38	8	20	4053.8	4144.00	0.18
30	1	38	5	49	3091.3	3569.00	0.16	64	1	38	8	31	3892.6	3835.00	0.16
31	1	38	5	58	3850.7	3930.00	0.06	65	1	38	8	40	3806.5	3978.00	0.12
32	1	38	6	7	4755.8	4577.00	0.27	66	1	38	8	42	3248.4	3536.00	0.06
33	1	38	6	8	4676.1	4518.00	0.15	67	1	38	8	43	3281.8	3774.00	0.05
34	1	38	6	9	4739.4	4604.00	0.05	68	1	38	8	46	3239.6	3640.00	0.11

Source: The Authors

Table 6.
Experimental results for version 2 of model A. Part II.

ID	J1	J2	J3	J4	Distance	Travel Time	Solver Time	ID	J1	J2	J3	J4	Distance	Travel Time	Solver Time
69	1	38	8	49	3250.6	3638.00	0.04	103	1	38	19	40	4452.1	4757.00	0.16
70	1	38	8	58	3933.6	3969.00	0.17	104	1	38	19	42	3814	4208.00	0.34
71	1	38	9	10	4497.7	4483.00	0.12	105	1	38	19	43	3827.6	4360.00	0.17
72	1	38	9	17	4618.9	4470.00	0.14	106	1	38	19	46	3845	4298.00	0.15
73	1	38	9	19	3701.7	3996.00	0.04	107	1	38	19	49	3827.4	4286.00	0.15
74	1	38	9	20	4195.4	4295.00	0.28	108	1	38	19	58	4142.8	4380.00	0.24

75	1	38	9	31	4034.2	3986.00	0.36	109	1	38	20	31	4358.6	4519.00	0.17
76	1	38	9	40	3948.1	4129.00	0.21	110	1	38	20	40	4587.3	4808.00	0.16
77	1	38	9	42	3390	3687.00	0.28	111	1	38	20	42	3853	4299.00	0.04
78	1	38	9	43	3423.4	3925.00	0.08	112	1	38	20	43	3869.9	4465.00	0.15
79	1	38	9	46	3381.2	3791.00	0.16	113	1	38	20	46	3877.3	4391.00	0.09
80	1	38	9	49	3392.2	3789.00	0.10	114	1	38	20	49	3864.6	4381.00	0.18
81	1	38	9	58	4060.4	4119.00	0.32	115	1	38	20	58	4266	4547.00	0.37
82	1	38	10	17	4251.4	4299.00	0.19	116	1	38	31	40	4440.4	4584.00	0.24
83	1	38	10	19	3990.4	4274.00	0.19	117	1	38	31	42	4564.3	4730.00	0.07
84	1	38	10	20	4483.7	4572.00	0.15	118	1	38	31	43	4670.5	5026.00	0.10
85	1	38	10	31	4185.7	4169.00	0.11	119	1	38	31	46	4532.3	4805.00	0.28
86	1	38	10	40	4224	4392.00	0.22	120	1	38	31	49	4418.2	4735.00	0.20
87	1	38	10	42	3601.5	3912.00	0.09	121	1	38	31	58	4955.9	4788.00	0.19
88	1	38	10	43	3617.5	4115.00	0.04	122	1	38	40	42	3950.8	4370.00	0.12
89	1	38	10	46	3588.5	4010.00	0.09	123	1	38	40	43	3978.2	4531.00	0.23
90	1	38	10	49	3596.1	4000.00	0.08	124	1	38	40	46	3974.8	4462.00	0.13
91	1	38	10	58	4151	4230.00	0.13	125	1	38	40	49	3962.2	4452.00	0.05
92	1	38	17	19	3454.6	3815.00	0.15	126	1	38	40	58	4316.3	4543.00	0.08
93	1	38	17	20	3948.3	4114.00	0.06	127	1	38	42	43	4540.4	4774.00	0.16
94	1	38	17	31	3787.1	3805.00	0.08	128	1	38	42	46	4434.1	4701.00	0.16
95	1	38	17	40	3701	3948.00	0.07	129	1	38	42	49	4241.7	4604.00	0.34
96	1	38	17	42	3142.9	3506.00	0.02	130	1	38	42	58	4434.7	4548.00	0.22
97	1	38	17	43	3176.3	3744.00	0.08	131	1	38	43	46	4420.3	4855.00	0.05
98	1	38	17	46	3134.1	3610.00	0.08	132	1	38	43	49	4268.1	4727.00	0.17
99	1	38	17	49	3145.1	3608.00	0.04	133	1	38	43	58	4477.6	4744.00	0.16
100	1	38	17	58	3904.5	3969.00	0.23	134	1	38	46	49	4353.4	4791.00	0.10
101	1	38	19	20	4375.6	4726.00	0.30	135	1	38	46	58	4475.3	4657.00	0.16
102	1	38	19	31	4288.8	4413.00	0.28	136	1	38	49	58	4533.7	4742.00	0.13

Source: The Authors.

Then, we generate 136 instances considering combinations of 4 municipalities using the potential municipalities given in Table 2.

Taking into account the port infrastructure of Coatzacoalcos (1) and Salina Cruz (38), they were fixed as the centers of the first two SEZs. The number between parentheses means the ID given in Table 2. The other two centers of SEZs were combined with the other potential municipalities, i.e., Cosoleacaque (2) and Jaltipan (5), Cosoleacaque (2) and Texistepec (6), Cosoleacaque (2) and Oluta (7), and so on to Cosoleacaque (2) and San Pedro Tapanatepec (58). The same was done with the rest of the potential municipalities.

Tables 3 and 4 show the experimental results for the 136 instances considering the version 1 of model A (distance). The first and ninth columns present the IDs of the instance; the second to fifth and tenth to thirtieth columns present the IDs of the municipalities established as a center of an SEZ (see Table 1); the sixth and fourteenth columns are the *distance* in km obtained by the model; the seventh and fiftieth columns are the *travel time* in minute*s* computed with Table A1 and using the solution obtained by the model; the eighth and last columns are the solution time in second*s* taken by the solver.

Tables 5 and 6 are very similar to Tables 3 and 4, just that these results are from version 2 of model A (time). The *travel time* in minutes is the solution of the model, and the *distance is* computed with a table similar to A1 but considering distance instead of time.

Fig. 2 presents the solution for the 136 instances comparing the *distance* for both versions of model A. The distance for the first version (circles) is the value of the objective function (column *distance* of Tables 3 and 4). The distance for the second version (rectangles) is the computed value considering the solution obtained by the model (column *distance* of Tables 5 and 6). The *X*-axis represents the instance number and the *Y*-axis is the value in km of the objective function. In this case, 11.76% of the instances have

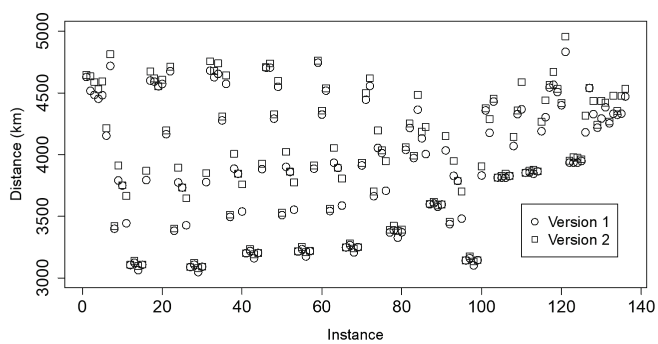

Figure 2. Solutions for the 136 instances comparing the *distance* in both versions of model A.
Source: The Authors.

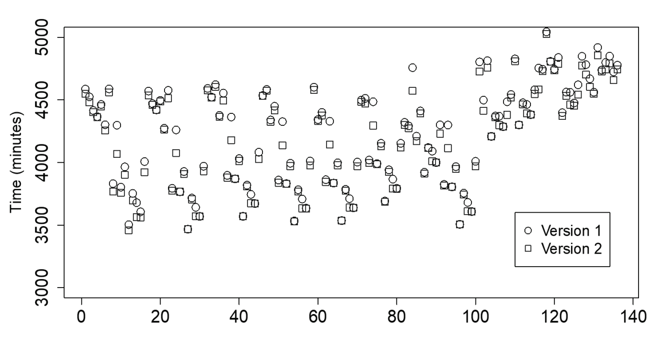

Figure 3. Solutions for the 136 instances comparing the *travel time* in both versions of model A.
Source: The Authors.

the same value for both versions while 88.24% have a smaller value in version 1. Note that in no instance does version 2 wins. This behavior is normal because the priority of version 1 is minimizing the distance instead of the time.

Fig. 3 shows the solution for the 136 instances comparing the *travel time* for both versions of model A. The travel time for the first version (circles) is the computed value using the solution of the model in joint with Table 8 (column *travel time* of Tables 3 and 4). The time for the second version (rectangles) corresponds to the value of the objective function (column *travel time* of Tables 5 and 6). The *X*-axis represents the instance number and the *Y*-axis is the value in minutes of the objective function. As in version 1, 11.76% of the instances have the same value for both versions of the model, while 88.24% of the instances have a smaller value in version 2. Note that in no instance does version 1 wins. This behavior is normal because the priority of the version 2 is minimizing the time.

Fig. 4 shows the configuration for version 1 of model A. The left side is the instance with the least distance, which takes *Coatzacoalcos, Salina Cruz, Jaltipan, and H. Ciudad de Juchitan de Zaragoza* as the centers of the SEZs. The right side is the instance with the greatest distance, which takes Coatzacoalcos*, Salina Cruz, San Pedro Tapanatepec,* and *Santo Domingo Tehuantepec* as the centers of the SEZs.

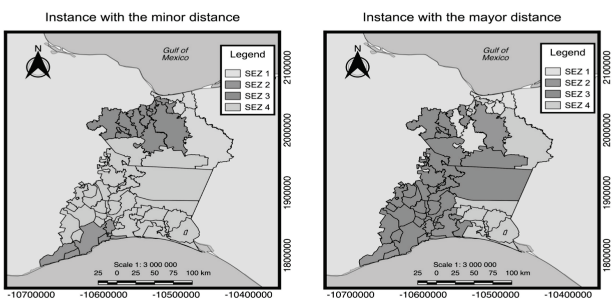

Figure 4. Configuations of SEZs minimizing the *distance* in version 1 of model A. The left side is the configuration with the least distance, and the right side is the configuration with the greatest distance.
Source: The Authors.

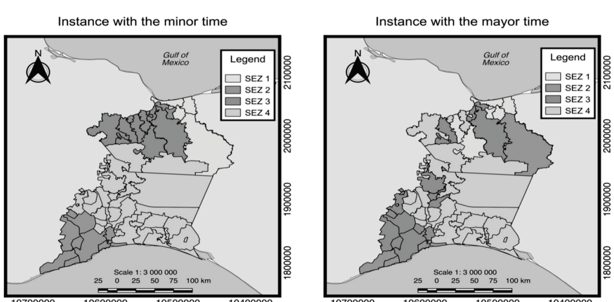

Figure 5. Configuration of SEZs minimizing the *travel time* in version 2 of model A. The left side is the configuration with the least time, and the right side is the configuration with the greatest time.
Source: The Authors.

Table 7.
Experimental results for both versions of model B.

Ver	J1	J2	J3	J4	Objective Function	Solution	Solver time
1	1	5	31	49	Distance	2868.6	2.40
2	5	17	19	31	Time	3279	4.15

Source: The Authors.

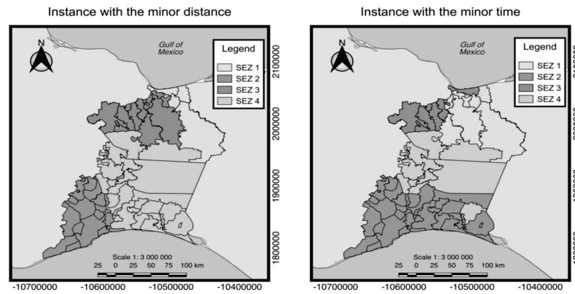

Figure 6. Configurations of SEZs for both versions of model B.
Source: The Authors.

The configuration for version 2 of model A is presented in Fig. 5. The left side is the instance with the smallest time, fixing *Coatzacoalcos, Salina Cruz, Cosoleacaque* and *Ciudad Ixtepec* as centers of the SEZs. The right side is the instance with the greatest time fixing, *Coatzacoalcos, Salina Cruz, Santo Domingo Tehuantepec* and *Asuncion Ixtaltepec* as the centers of the SEZs.

4.2. Model B

The results for both versions of model B are shown in Table 7. The first column gives the version of the model. From the second to fifth columns are the municipalities which were established as the centers of the SEZs (ID of Table 2). The sixth column represents the objective of the version: *distance* or *time*. The seventh column is the value of the objective function in km or minutes. The last column is the time in seconds needed to obtain the optimal solution.

Fig. 6 shows the configuration given by both versions of model B. The left side is the result of version 1, which takes *Coatzacoalcos, Jaltipan, Santo Domingo Tehuantepec* and *Union Hidalgo* as the centers of the SEZs. The right side is the result for version 2, which takes *Jaltipan, Minatitlan, Matias Romero Avedaño* and *Santo Domingo Tehuantepec* as the centers of the SEZs.

5. Conclusions

In this article, we presented a new approach for the delineation of Special Economic Zones (SEZs). This approach relies on two mathematical models of Integer Linear Programming which consider the federal laws imposed by the government and the natural and logistical characteristics of the region. In the first model, the centers of the SEZs are pre-established according to the minimum number of zones required considering the population and infrastructure of the region. The second model considers the same parameters as the first one, but chooses all the centers of the SEZs. Each model has two versions, the first one minimizes the distance between municipalities and SEZs, and the second one minimizes time.

Experimental results applied to the region of the Isthmus of Tehuantepec, Mexico, validate the method and show several configurations for the design of SEZs, which allows the establishment of negotiations between the municipalities and therefore the support of the local government in the implementation of these zones.

Some extensions of this approach to more complex model such as a bi-objective mathematical formulation are currently under study.

Acknowledgments

This work was supported by the Chairs Program of the Mexican National Council of Science and Technology CONACYT.

Appendix 1

Table A1.
Time in *minutes* from municipalities (rows) to potential centers of SEZs (columns). The IDs correspond to those ID given in Table 1.

ID	1	2	5	6	7	8	9	10	17	19	20	31	38	40	42	43	46	49	58
1	0	36	49	75	59	58	81	116	29	188	187	253	271	213	238	253	241	242	260
2	38	0	17	46	42	41	64	99	20	171	169	236	254	196	221	236	224	225	266
3	48	15	17	46	51	52	74	110	30	181	180	246	265	207	232	246	234	236	277
4	49	14	18	47	52	53	75	111	31	183	181	247	266	208	233	247	235	237	278
5	51	18	0	32	37	40	62	98	33	170	168	235	253	195	220	234	222	224	265
6	80	47	32	0	18	33	55	91	62	163	161	228	246	188	213	228	215	217	258
7	67	49	34	18	0	19	41	77	50	149	147	214	232	194	199	214	201	203	244
8	61	43	39	31	16	0	28	61	43	133	131	198	216	158	183	198	185	187	228
9	83	66	61	54	38	27	0	74	66	146	145	211	229	171	196	211	199	201	241
10	119	101	97	90	74	60	75	0	102	85	84	150	169	110	135	150	138	140	181
11	97	83	97	92	107	106	128	149	71	221	219	286	304	246	271	286	273	275	316
12	251	252	265	265	276	274	297	224	246	213	212	278	296	238	263	278	266	267	308
13	30	40	53	79	63	62	84	120	34	191	190	256	275	217	242	256	244	246	252
14	38	29	43	69	53	51	74	110	24	181	180	246	265	206	232	246	234	236	244
15	50	45	58	84	68	67	89	125	39	197	195	261	280	222	247	261	249	251	248
16	68	69	82	108	92	91	114	159	63	221	220	286	304	246	271	286	274	275	255
17	28	19	33	59	43	41	64	100	0	231	170	236	255	196	221	236	224	226	255
18	66	67	80	106	90	89	111	147	61	219	217	284	302	244	269	284	271	273	231
19	190	173	169	161	145	131	146	84	173	0	52	82	101	27	68	82	70	72	113
20	189	172	168	160	144	130	145	83	172	52	0	117	135	77	102	117	105	106	147
21	221	204	199	292	176	162	177	115	204	33	84	99	117	7	84	98	86	88	129
22	295	278	274	266	250	236	251	189	278	124	158	89	107	134	73	88	104	105	146
23	306	289	285	277	261	247	262	200	289	135	169	100	118	145	84	99	115	116	157
24	293	276	271	264	248	234	249	187	276	122	156	65	83	132	72	87	95	103	144
25	363	346	342	334	318	304	319	257	346	192	226	121	140	202	142	158	153	173	214
26	269	252	248	240	224	210	225	163	252	98	132	27	46	108	48	64	59	79	120
27	289	271	267	260	244	230	245	183	272	118	151	47	66	128	68	84	79	99	140
28	323	305	301	293	278	264	278	216	305	151	185	81	73	162	102	116	113	132	173
29	313	296	291	284	268	254	269	207	296	142	176	72	63	152	92	107	103	123	164
30	341	323	319	312	296	282	297	234	324	169	203	99	118	180	120	136	131	151	191
31	255	238	233	226	210	196	211	149	238	84	118	0	27	94	34	39	33	56	106
32	250	233	228	221	205	191	206	144	233	79	113	15	34	89	29	41	36	59	101
33	258	241	237	229	213	199	214	152	241	87	121	52	70	97	19	34	53	68	109
34	247	230	226	218	202	188	203	141	230	76	110	41	59	86	25	40	56	57	98
35	239	222	217	210	194	180	195	133	222	68	102	33	51	78	17	32	48	49	90
36	268	251	247	239	223	209	224	162	251	97	131	46	71	107	34	18	36	59	116
37	278	261	256	249	233	219	224	172	261	107	141	26	25	117	57	53	47	70	129
38	262	255	255	243	227	213	228	166	255	101	135	29	0	111	52	64	59	82	123
39	264	187	243	235	219	205	220	158	247	99	127	12	37	103	41	37	32	55	113
40	216	198	194	187	171	157	172	109	199	27	78	93	112	0	79	93	81	83	124
41	209	192	187	180	164	150	165	103	192	38	72	86	105	8	72	86	74	76	117
42	244	226	222	215	199	185	200	138	227	72	107	46	64	83	0	19	39	54	94
43	254	227	233	225	209	195	210	148	237	83	117	38	63	93	19	0	22	45	103
44	244	227	222	215	199	185	200	148	227	73	107	36	62	83	28	15	18	35	92
45	255	237	233	226	210	196	211	148	238	83	117	38	64	94	45	28	17	40	103
46	239	222	218	210	194	180	195	133	222	68	102	33	58	78	39	23	0	25	88
47	305	288	283	276	260	246	261	199	288	134	168	53	52	144	84	84	78	101	156
48	281	263	259	251	236	222	236	174	263	109	143	85	111	120	87	75	57	38	93
49	243	226	222	214	198	184	199	137	226	72	106	55	80	82	50	44	26	0	76
50	235	217	213	205	190	176	190	128	217	63	97	56	74	74	41	53	41	28	60
51	270	253	249	241	225	211	226	164	253	99	133	91	110	109	76	89	77	62	103
52	276	259	255	247	231	217	232	170	259	105	139	122	140	115	107	121	109	111	152
53	245	228	224	216	200	187	201	139	228	74	108	66	85	84	52	64	52	39	47
54	280	263	259	251	235	221	236	164	263	109	143	101	120	119	86	99	87	73	50
55	290	275	271	263	247	233	248	186	275	121	155	113	132	131	98	111	99	85	61
56	269	251	247	239	224	210	224	162	251	97	131	90	108	108	75	87	75	62	39
57	264	246	242	234	219	202	219	157	246	92	126	85	103	103	70	82	70	57	22
58	263	264	260	252	237	223	237	175	258	110	144	103	121	121	88	100	88	75	0
59	271	275	270	263	247	233	248	186	266	121	155	113	131	131	98	111	98	85	18

Source: The Authors.

References

[1] Farole, T. and Akinci, G., Special economic zones: progress, emerging challenges and future directions. The World Bank, Washington D.C., 2015. DOI: 10.1596/978-0-8213-8763-4
[2] Akinci, G. and Crittle, J., Special economic zones: performance, lessons learned, and implications for zone development, The World Bank, Washington, D.C., 2008.
[3] Zeng, D., How do special economic zones and industrial clusters drive China's rapid development?, The World Bank, Washington, D.C., 2011. DOI: 10.1596/1813-9450-5583
[4] Fan, C. and Scott, A.J., Industrial agglomeration and development: a survey of spatial economic issues in East Asia and a statistical analysis of Chinese regions. Economic Geography, 79(3), pp. 295-319, 2003. DOI: 10.1111/j.1944-8287.2003.tb00213.x
[5] Yeung, J.L. and Kee, G., China's special economic zones at 30. Eurasian Geography and Economics, 50(2), pp. 222-240, 2009. DOI: 10.2747/1539-7216.50.2.222
[6] Zhong, J., The course, achievements and inspirations of the reform and opening-up of the shenzhen special economic zone. In: Studies on China's special economic zones, Springer Singapore, Ch. 3, 2017, pp. 23-39. DOI: 10.1007/978-981-10-3704-7_3
[7] Nel, E. and Rogerson, C., Special economic zones in South Africa: reflections from international debates. Urban Forum Springer, 24(2), pp. 205-217, 2013. DOI: 10.1007/s12132-012-9184-7
[8] Palit, A. and Bhattacharjee, S., Special economic zones in India: myths and realities. Anthem Press, New Delhi, 2008, pp. 107-111.
[9] Aggarwal, A., Hoppe, M. and Walkenhorst, P., Special economic zones in South Asia: industrial islands or vehicles for diversification? The World Bank, Washington, D.C., 2008.
[10] Wang, J., The economic impact of special economic zones: evidence from Chinese municipalities. Journal of Development Economics, 101, pp. 133-147, 2013. DOI: 10.1016/j.jdeveco.2012.10.009
[11] Aggarwal, A., Special economic zones: revisiting the policy debate. Economic and Political Weekly, 41(43/44), pp. 4533-4536, 2016.
[12] Mukherjee, A., Pal, P., Deb, S., Ray, S. and Goyal, T.M., Special economic zones in india: status, issues and potential. Berlin: Springer Verlag, 2016.
[13] Chaudhuri, S. and Yabuuchi, S., Formation of special economic zone, liberalized DFI policy and agricultural productivity. International Review of Economics and Finance, 19(4), pp. 779-788, 2010. DOI: 10.1016/j.iref.2010.02.004
[14] Ríos-Mercado, R.Z. and Escalante, H.J., GRASP with path relinking for commercial districting. Expert Systems with Applications, 44(201), pp. 102-113, 2016. DOI: 10.1016/j.eswa.2015.09.019
[15] Pukelsheim, F., Ricca, F., Simeone, B., Scozzari, A. and Serafini, P., Network flow methods for electoral systems. Networks, 59(1), pp. 73-88, 2012. DOI: 10.1002/net.20480
[16] Ricca, F. and Simeone, B., Local search algorithms for political districting. European Journal of Operational Research, 189(3), pp. 1409-1426, 2008. DOI: 10.1016/j.ejor.2006.08.065
[17] Bozkaya, B., Erkut, E. and Laporte, G., A tabu search heuristic and adaptive memory procedure for political districting. European Journal of Operational Research, 144(1), pp. 12-26, 2003. DOI: 10.1016/S0377-2217(01)00380-0
[18] Forman, S.L. and Yue, Y., Congressional districting using a tsp-based genetic algorithm. In: Genetic and Evolutionary Computation Conference, Springer-Verlag, Berlin, 2003, pp. 2072-2083. DOI: 10.1007/3-540-45110-2_104
[19] Mehrotra, A., Johnson, E.L. and Nemhauser, G.L., An optimization based heuristic for political districting. Management Science, 44(8), pp. 1100-1114, 1998.
[20] Browdy, M.H., Simulated annealing: an improved computer model for political redistricting. Yale Law and Policy Review, 8(1), pp. 163-179, 1990.
[21] Zoltners, A.A. and Sinha, P., The 2004 ISMS practice prize winner-sales territory design: thirty years of modeling and implementation. Marketing Science, 24(3), pp. 313-331, 2005. DOI: 10.1287/mksc.1050.0133
[22] Zoltners, A.A. and Sinha, P., Sales territory alignment: a review and model. Management Science, 29(11), pp. 1237-1256, 1983. DOI: 10.1287/mnsc.29.11.1237
[23] Drexl, A. and Haase, K., Fast approximation methods for sales force deployment. Management Science, 45(10), pp. 1307-1323, 1999. DOI: 10.1287/mnsc.45.10.1307
[24] Albornoz, V.M., Cid-Garcia, N.M., Ortega, R. and Rios-Solis, Y.A., A hierarchical planning scheme based on precision agriculture. In: Handbook of Operations Research in Agriculture and the Agri-Food Industry, Berlin: Springer-Verlag, 2015, pp. 129-162. DOI: 10.1007/978-1-4939-2483-7_6
[25] Cid-Garcia, N.M., Albornoz, V., Rios-Solis Y.A. and Ortega, R., Rectangular shape management zone delineation using integer linear programming. Computers and Electronics in Agriculture, 93, pp. 1-9, 2013. DOI: 10.1016/j.compag.2013.01.009
[26] Muyldermans, L., Cattrysse, D.D., Oudheusden, V. and Lotan, T., Districting for salt spreading operations. European Journal of Operational Research, 139(3), pp. 521-532, 2002. DOI: 10.1016/S0377-2217(01)00184-9
[27] Kalcsics, J., Districting problems. In: Location Science, Springer-Verlag, Berlin, 2015, pp. 595-622. DOI: 10.1007/978-3-319-13111-5_23
[28] Kalcsics, J., Nickel, S., and Schröder, M., Towards a unified territorial design approach applications, algorithms and GIS integration. Top 13(1), pp. 1-56, 2005. DOI: 10.1007/BF02578982
[29] Duque, J.C., Ramos, R. and Suriñach, J., Supervised regionalization methods: a survey. International Regional Science Review, 30(3), pp. 195-220, 2007. DOI: 10.1177/0160017607301605
[30] Ricca, F., Scozzari, A. and Simeone B., Political districting: from classical models to recent approaches. Annals of Operations Research, 204 (1), pp. 271-299, 2013.
[31] Cornuéjols, G., Nemhauser, G.L. and Wolsey L.A., The uncapacitated facility location problem, Tech. rep., DTIC Document, 1983.

N.M. Cid-Garcia, received the PhD. degree in Systems Engineering in 2016 from the Autonomous University of Nuevo Leon, Mexico. Since 2016 he has been a full researcher with the Chairs Program of the Mexican National Council of Science and Technology (CONACYT) in the National Laboratory of Geointelligence, CentroGeo, Aguascalientes, Mexico. His research interests include mathematical modeling; application and theory of operations research techniques; and the design, development, and analysis of efficient approximate and exact algorithms. Some application areas include delineation of site-specific management zones, agricultural production planning, special economic zones, and 2D packing problems.
ORCID: 0000-0003-0793-073X

N. Alvarez-Jarquin, received the PhD in Physics from the University of Paris-Sud 11, France in 2015. Since 2016 she has been a full researcher with the Chairs Program of the Mexican National Council of Science and Technology (CONACYT) in the National Laboratory of Geointelligence, CentroGeo, Aguascalientes, Mexico. Her research interests include switched systems, dynamical systems, implicit systems, the stability of nonlinear time-varying systems, and the Internet of Things.
ORCID: 0000-0003-3367-5517

M.L. Ruvalcaba-Sánchez, received the PhD. degree in Logistics and Supply Chain Management from UPAEP, Puebla, Mexico in 2011. She has worked as a professor for several universities. Currently, she is a full researcher with the Chairs Program of the Mexican National Council of Science and Technology (CONACYT) in the National Laboratory of Geointelligence, CentroGeo, Aguascalientes, Mexico. Her research interests include software engineering, discrete simulation, computational optimization and algorithms of approximation for logistics, supply chain, and industrial problems and statistical methods.
ORCID: 0000-0002-4225-9032

J.G. Correa-Medina, received the PhD. degree in Logistics and Supply Chain Management from UPAEP, Puebla, Mexico in 2011. From 2003 through 2015, he worked as a professor for several universities. Currently, he works as a full researcher on Mobility and Logistics in the National Laboratory of Geointelligence, CentroGeo, Aguascalientes, Mexico. His research interests include heuristics and metaheuristics for optimization, supply chain and logistics, mobility, facility location, territorial design, and computer viruses.
ORCID:0000-0003-0059-1931