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A BI-OBJECTIVE APPROACH TO DETERMINE THE INFLUENCE AREA IN SPECIAL ECONOMIC ZONES

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Abstract: In this article, we present a methodology to determine the influence area in Special Economic Zones (SEZ). A SEZ is a geographically delimited area located within the national boundaries of a country that offers several fiscal and laboral benefits to improve the productivity of the region according to its physical location. The influence area of the SEZ is composed of the near urban and rural populations that are susceptible to receive several economic, social, and technological benefits. That is derived from the activities carried out in the zone and from the complementary policies and actions planned in the Development Program that will also support the development of several services such as logistics, financial, tourism, and software, which are complementaries to the economic activities of the zone. The SEZ and their influence area are generally formed by one or more municipalities that share a particular productive vocation such as agro-industry, manufacturing, petrochemicals, and development of information technologies. In this study, we propose a methodology based on a bi-objective mathematical formulation of Integer Linear Programming to determine the influence area of the SEZ considering the population, the distance and time between municipalities and SEZ, the productive vocation of the municipalities, and the infrastructure of the region. Experimental results, applied to the SEZ established in the region of the Isthmus of Tehuantepec, Mexico, empirically validate the methodology and make a comparison with the SEZ and their influence area determined by the Mexican government.

Keywords: Influence area, Integer linear programming, Bi-objective approach, Special Economic Zones.

INTRODUCTION

A Special Economic Zone (SEZ) is a geographically delimited area contained within the boundaries of a country to offer several fiscal and laboral benefits with the purpose to improve the productivity of the region. The concept of influence area is referring to the urban and rural populations close to the SEZ that are susceptible to receive several economic, social, and technological benefits, which are derived from activities carried out in the zone and from complementary policies and actions foreseen in its the Development Program. The influence area will also support the development of logistics, financial, tourism, and software development services that are complementaries to the economic activities of the zone. The SEZ and its influence area share a particular productive vocation (according to the requirements and specifications of each country) such as agroindustry, automotive, manufacturing, petrochemicals, machinery and equipment, and information technologies (Akinci and Crittle, 2008; Shakya, 2009; Walsh, 2015; Zeng, 2011a).

The SEZ aim is to achieve one or more of the following four policy objectives: *a)* to attract foreign direct investment (FDI), *b)* to serve as pressure valves to alleviate large-scale unemployment using job-creating programs, *c)* to support a wider economic reform strategy allowing to develop and diversify exports, and *d)* to serve as experimental laboratories for the application of new policies and approaches (Akinci and Crittle, 2008; Farole and Akinci, 2011).

China is the pioneer in the creation of special economic zones, which originally were established on the Pacific coast to test a social experiment –the efficacy of market-oriented economic reforms in a controlled environment. The first four were established in 1980 in *Shenzen*, *Zhuai*, *Shantou* (Guangdong Province), and *Xiamen* (Fujian Province). In

1988, the fifth was established in the entire province of *Hainan*, and in 1989 and 2006, *Shanghai Pudong New Area* and *Tianjin Binhai New Area* were granted such status as well. These SEZ were located at strategic points in the country to allow the transfer of goods, and away from the center of Beijing's political power to minimize potential risks and political interference. *Shenzen* has been the most developed of all of them (Chu, 1987; Nishitateno, 1983; Sit, 1985; Wong and Chu, 1984; Yeung, Lee and Kee, 2009; Zeng, 2011b).

The SEZ have been successful in the economy of China, which has motivated other countries such as India, Bangladesh, Mauritius, Madagascar, Tunisia, and North Korea to establishes their ones to provide more and better opportunities to compete in the international market. However, in some countries such as Bangladesh, Ghana, Lesotho, Nigeria, and Tanzania, the establishment of zones has not been entirely successful (low levels of foreign investment, exports, and job creation). The main challenges in these countries include access to land, regulatory barriers, resettlement and coordination issues, and lack of external infrastructure (Ambroziak and Hartwell, 2018; Dohrmann, 2008; Farole, 2011a; Gerald, Dumezweni and Blessing, 2017; Hsu, Lai and Lin, 2013; Jenkins, Kennedy, Mukhopadhyay and Pradhan, 2015; Lee, 2015; Liu, Shi, Zhang, Tsai, Zhai, Chen and Wang, 2018; Maslikhina, 2016; RoyChoudhury, 2010; Sosnovksikh, 2016; Sosnovskikh, 2017; Wang, 2013; Zeng, 2011b, 2016).

There exist several common key elements that have contributed to the success of the SEZ in other countries, e.g., a strong commitment to reform and pragmatism form top leadership; preferential policies and institutional autonomy; strong support and proactive participation of governments; foreign direct investment; technology learning, innovation, upgrading, and strong links with the domestic economy; innovative cultures; clear objectives, benchmarks, and intense competition; and location advantages (Farole, 2011a,b; Moberg, 2015; Zeng, 2011b).

However, also we can find some common obstacles that hinder the success of SEZ such as poor site locations for competitiveness, entailing heavy capital expenditures; uncompetitive policies—reliance on tax holidays, rigid performance requirements, poor labor policies, and practices; poor zone development practices—inappropriately designed or over-designed facilities, inadequate maintenance, and promotion practices; subsidized rent and other services; cumbersome procedures, and controls; inadequate administrative structures or too many bodies involved in zone administration; and weak coordination between private developers and governments in infrastructure provision. The common mistake at the root of many of these obstacles is a lack of effective coordination, both in terms of the parties involved and various physical and procedural aspects of the zone itself. Therefore, the success of SEZ requires a very capable government and a well-functioning market system, at least inside the zone or park (Dhingra, Singh and Sinha, 2009; Akinci and Crittle, 2008; Zeng, 2011b).

Although the SEZ aim is to improve the local economy of a country, they have other indirect advantages and disadvantages in the region, e.g., narrowing regional disparity, reducing ethnic tensions, fighting terrorism, and balancing the flow of goods (Chou and Ding, 2015; Shankar, 2007; Zhou, Wang, Mai and Tian, 2016).

Recently, the Mexican government enacted a Federal Law for the creation of Special Economic Zones in the states with the highest index of extreme poverty: Puerto Chiapas, Chiapas; Lazaro Cardenas-La

Union, Michoacan-Guerrero; Salina Cruz, Oaxaca; Coatzacoalcos, Veracruz; and Puerto Progreso, Yucatan. The expectations of these SEZ is the generation of about 280000 jobs with more than 50 companies and their suppliers, which will benefit the SEZ and their influence area generating permanent jobs, industrial upgrading, labor productivity growth, and productive investments (Dominguez Villalobos and Brown Grossman, 2017).

In several countries, the SEZ have been established directly by the local government. For these cases, some comparative advantages such as geography, infrastructure, labor market, and regional strategic alliances were considered (e.g., Indonesia-Malaysia-Singapore Growth Triangle). Major SEZ around the world were, generally, established by an international organism, e.g., the Mundial Bank or the Interamerican Development Bank, and they were located on coasts because they are geographically strategic locations for the flow of goods and the establishment of tourist services. In Colombia, for example, the SEZ were established directly by the government by a decree after consultation between entities public, private, and social sectors. In Costa Rica, SEZ were promoted by the Association Agency for Development of the Huetar Norte Region as a mechanism to strengthen competitiveness. In Panama, the SEZ arises like a regulatory mechanism for conflict of interests (Centro de Estudios de las Finanzas Públicas, 2017). In China, zones emerge as an economic policy experiment to explore new systems of government with an opportunity to modernize existing administrative mechanisms (Akinci and Crittle, 2008). However, there are not antecedents of location subject to restrictions of infrastructure, population, and productive vocation. Neither on predefinition of influence area, as in the case of Mexico.

Some methodologies, as operations research techniques, can be implemented to delineate special economic zones considering the characteristics mentioned previously. These methods have a broad applicability in similar problems to the design of SEZ, such as: *a) Design of territories,* where small geographic basic units are grouped into larger cluster called territories (Ríos-Mercado and Escalante, 2016), which have several applications in political districting (Forman and Yue, 2003; Bozkaya, Erkut and Laporte, 2003; Forman and Yue, 2003; Ricca and Simeone, 2008; Pukelsheim, Ricca, Simeone, Scozzari and Serafini, 2012), sales territory (Zoltners and Sinha, 2005; Lei, Laporte, Liu and Zhang, 2015; Ríos-Mercado and Escalante, 2016), power districting (Bergey, Ragsdale and Hoskote, 2003; De Assis, Franca and Usberti, 2014) and public services (Muyldermans, Cattrysse, Van Oudheusden and Lotan, 2002). b) Design of site-specific management zones in agricultural fields, where from a set of soil samples an agricultural field is divided in small regions, which must be homogeneous with respect to a specific soil property (Albornoz, Cid-García, Ortega and Ríos-Solís, 2015; Cid-Garcia, Albornoz, Rios-Solis and Ortega, 2013); and c) Location of facilities, where a site for some facility must be chosen (resources) in order to minimize the cost of satisfying some set of demands (customers) with respect to some set of constraints or a particular criterion (Buckley, 1987; Farahani and Hekmatfar, 2009).

In this study, we propose a methodology based on operations research techniques, specifically in a bi-objective mathematical formulation of Integer Linear Programming (BILP), to delineate the influence area of the SEZ. The population of the region, the distance and time between municipalities to SEZ, the productive vocation, and the infrastructure of the region are considered. Experimental results applied to the region of the Isthmus of Tehuantepec, Mexico, validate the methodology and make an analysis with respect to the SEZ determined by the Mexican government. To the best of our knowledge, this is one of the first mathematical models used to delineate Special Economic Zones.

The rest of this paper is as follows. In Section 2 the materials and methods to determine the influence area of the SEZ are presented. Section 3 shows the experimental results applied to the Isthmus of Tehuantepec, Mexico, and Section 4 gives some conclusions and recommendations of the work.

MATERIAL AND METHODS

In this section, we present the information and the characteristics of our bi-objective mathematical model. Furthermore, we present a case study about the region of the Isthmus of Tehuantepec, Mexico. However, the methodology could be implemented for any country if all the requirements for the model are satisfied.

MATHEMATICAL FORMULATION

To determine the influence area in a SEZ, we propose a bi-objective mathematical formulation of integer linear programming. The first objective consists in maximizing the amount of product (according to a selected productive vocation) in the special economic zones. The second objective consists in minimizing the number of municipalities in the influence area of the SEZ. In Section 3, we show that the objective functions conflict one with each other.

Formalizing, let I be the set of municipalities, J the set of SEZ established by the Mexican government and, K the set of economic activities. For each municipality i the production by economic activity k is $Prod_i^k$, and the population by municipality is p_i. The distance and time from a municipality ^{i} to a specific SEZ j are defined by d_{ij} and t_{ij}, respectively. For our case study, these parameters are the real distance and travel time, between municipalities, according to the Secretariat of Communications and Transport. Furthermore, there exists a limit for the minimum of population LP, a demand to satisfy for each economic activity k in each SEZ j, $Demand_j^k$, and a maximum of distance and time from municipality i to SEZ j, UD and UT, respectively. The decision variables for the mathematical formulation are:

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

$$y_{ij}^k = \text{The amount of product } k \text{ to send from municipality } i \text{ to SEZ } j.$$

For each productive vocation k of the SEZ the next mathematical model is executed:

$$\left\{ \max z_1 = \sum_{i\epsilon I} \sum_{j\epsilon J} y_{ij}^k \text{ , } \min z_2 = \sum_{i\epsilon I} \sum_{j\epsilon J} x_{ij} \right\} \quad (1)$$

Subject to

$$\sum_{j\epsilon J} x_{ij} \leq 1, \qquad \forall i\epsilon I \quad (2)$$

$$\sum_{i\epsilon I} p_i x_{ij} \geq LP, \qquad \forall j\epsilon J \quad (3)$$

$$y_{ij}^k \leq Prod_i^k x_{ij} \qquad \forall i\epsilon I, \forall j \in J \quad (4)$$

$$\textstyle\sum_{j\epsilon J} y_{ij}^k \leq Prod_i^k \quad \forall i\epsilon I \quad (5)$$

$$\sum_{j\epsilon J} y_{ij}^k \leq Demand_j^k \qquad \forall i\epsilon I \quad (6)$$

$$D_{ij} x_{ij} \leq UD \qquad \forall i\epsilon I, \forall j\epsilon J \quad (7)$$

$$T_{ij} x_{ij} \leq UT \qquad \forall i\epsilon I, \forall j\epsilon J \quad (8)$$

$$x_{ij} \, \epsilon \{0,1\} \qquad \forall i\epsilon I, \forall j\epsilon J \quad (9)$$

$$y_{ij}^k \geq 0 \qquad \forall i\epsilon I, \forall j\epsilon J \quad (10)$$

where equation (1) represents the bi-objective function: the first one maximizes the production of each economic activity in each SEZ, and the second one minimizes the number of municipalities in the SEZ. Constraints (2) ensure that each municipality is assigned to only one SEZ. Constraints (3) guarantee the minimum of population for each economic zone. Constraints (4) ensure that a municipality can send product to a special economic zone only if this is assigned to it. Constraints (5) determine that a municipality cannot send more product than the available. Constraints (6) guarantee to satisfy the demand imposed for the SEZ for each economic activity (if this exists). Constraints (7) and (8) ensure the distance and time from a municipality to a SEZ must not be longer than a specific distance / time parameter. It is desirable that people do not invest more than 25% of their workday in travel between their home and work. While the agricultural products require short travel times to preserve because of are transporting on vehicles without refrigeration. In this sense, the distance parameter was fixed to 100 km and the time parameter to 120 minutes (do Nascimento Nunes, Nicometo, Emond, Melis and Uysal, 2014; Christian, 2012). Finally, in (9) and (10) the nature of the variables is declared.

For bi-objective problems there does not exist only a specific solution, i.e., there exist many solutions that optimize both objectives. This solution set is known as the set of non-dominated solutions (for a non-dominated solution, there are no other solutions that improve an objective without worsening the other one), which represents the *trade-off* set satisfying both objectives. The *trade-off* curve is known as the Pareto front and we compute it using the $\epsilon_{\text{-constraint}}$ method (Ehrgott, 2005; Marler and Arora, 2004). This method consists in optimizing one of the objective functions while the other one is used as a constraint in the model.

If we apply the $\epsilon_{\text{-constraint}}$ method for our problem, with the assumption we have a limited number of municipalities that are fixed for each SEZ (removing the second objective function), then, we have the following formulation for each productive vocation *k*:

$$\max z_i = \sum_{i \epsilon I} \sum_{j \epsilon J} y_{ij}^k \qquad (11)$$

Subject to

$$(2\text{–}10) \qquad (12)$$

$$\sum_{j \epsilon J} x_{ij} \leq \epsilon, \qquad \forall i \epsilon I \qquad (13)$$

where the ϵ-value is a parameter that indicates an upper bound established for the second objective. By using variations on the ϵ-value, the set of efficient solutions for the problem can be obtained (the Pareto front).

SPECIAL ECONOMIC ZONES IN MEXICO: A CASE STUDY

The Federal Law for the creation of SEZ was established by the Mexican government in 2016 to generate permanent jobs, industrial upgrading, labor productivity growth and productive investments in the states with the highest level of poverty. The ranking of the ten states in Mexico with the highest index poverty (second and third columns), moderate poverty (fourth and fifth columns), and extreme poverty (sixth and seventh columns) are showed in Table 1.

Between 2016 and 2017 the Mexican government established a serie of decrees to create SEZ in the ten states with the highest index of poverty: Chiapas, Oaxaca, Michoacan, Guerrero, Veracruz, Yucatan, Campeche, and Tabasco (Diario Oficial de la Federación, 2017a,b,c,d,e, 2018a,b). Each decree is region-specific for each state and gives the minimum requirements for the creation of the SEZ, e.g., the municipality(s) and the polygon where the SEZ is going to be created, the municipalities corresponding to its influence area, the productive vocation of

Ranking	Poverty	Percentage	Moderate P.	Percentage	Extreme P.	Percentage
1	Chiapas	76.2	Tlaxcala	52.4	Chiapas	31.8
2	Oaxaca	66.8	Puebla	48.4	Oaxaca	28.3
3	Guerrero	65.2	Zacatecas	46.6	Guerrero	24.5
4	Puebla	64.5	Michoacán	45.2	Veracruz	17.2
5	Michoacán	59.2	Morelos	44.4	Puebla	16.2
6	Tlaxcala	58.9	Chiapas	44.4	Michoacán	14.0
7	Veracruz	58.0	México	42.4	Hidalgo	12.3
8	Hidalgo	54.3	Hidalgo	42.0	Campeche	11.1
9	Zacatecas	52.3	Guanajuato	41.0	Tabasco	11.0
10	Morelos	52.3	Veracruz	40.9	Yucatán	10.7

Table 1. The ranking of the ten states in Mexico with the highest index of poverty, moderate poverty and extreme poverty (2014).

SEZ	Productive vocation	Municipalities	Influence Area	Hab. SEZ	Hab. IA	Total Hab.
Salina Cruz	Agroindustry, electrical/electronic, machinery and equipmment, metal-mechanical, and textile.	Salina Cruz (Oax.)	—-	89211	0	89211
Coatzacoalcos	Industries.	Coatzacoalcos, Ixhuatlan del Sureste, and Nanchital de Lazaro Cardenas del Rio (Ver.)	Minatitlan, Cosoleacaque, Oteapan, Chinameca, Jaltipan, and Zaragsoza (Ver.)	365026	372381	737407
Puerto Chiapas	Agriculture, commerce, temporary housing and manufacturing services.	Tapachula (Chis.)	Tuxtla Chico, Suchiate, Huehuetan, Mazatan, Frontera Hidalgo, and Metapa (Chis.)	348156	165035	513191
Lazaro Cardenas- La Union	Agroindustry, automotive, metal-mechanical and steel industry.	Lazaro Cardenas (Mich.); La Union de Isidoro Montes de Oca (Gro.)	Zihuatanejo de Azueta (Gro.)	209617	124824	334441
Progreso	Information and communication technologies, telecommunications, software development and commercialization. Manufacturing: electrical and electronic, glass, plastic, machinery and equipment, metal-mechanical and jewelry.	Progreso (Yuc.)	Kanasin, Uman, Hunucma, Merida, Conkal, Chicxulub Pueblo, and Ucu (Yuc.)	59122	1092025	1151147
Champoton	Agroindustry, chemical and plastic manufacturing.	Champoton (Cam.)	Carmen and Campeche (Cam.)	90244	531328	621572
Paraiso	Agroindustry, machinery and equipmment.	Paraiso (Tab.)	Comalcalco (Tab.)	94375	201654	296029

Table 2 Short description of the SEZ in Mexico.

the region, the maximum and minimum of population, and the fiscal and laboral benefits.

Table 2 gives a short description for each SEZ. The first column represents the SEZ. The second column is the productive vocation. The third column shows the municipalities where the SEZ is going to be established. The fourth column represents the municipalities that define the influence area. The fifth and sixth columns are the population of the municipalities in the SEZ and the influence area, respectively. The last column is the total of population.

The SEZ established by the Mexican government are presented in Fig. 1. The red zone represents the municipalities where the special economic zones are established, and the green zone represents the municipalities corresponding to theirinfluence area. TheSEZ are: Lazaro Cardenas, Michoacan–La Union, Guerrero; Salina Cruz, Oaxaca; Coatzacoalcos, Veracruz; Puerto Chiapas, Chiapas; Puerto Progreso, Yucatan; Champoton, Campeche; and Paraiso, Tabasco. Notice the SEZ of Salina Cruz is the only one without an influence area established.

In this work, we focussed on the SEZ corresponding to the Isthmus of Tehuantepec: Salina Cruz, Oaxaca and Coatzacoalcos, Veracruz. The Isthmus of Tehuantepec is the narrowest part of the Mexican Republic between the Pacific Ocean and the Gulf of Mexico. It is a region with vast natural and cultural wealth, productive advantages, and geopolitical importance as a place of transit and commerce since prehispanic times. However, this is one of the poorest regions of the country despite having been the scene of multiple programs and projects to improve its conditions for decades. Although the region has not been developing, these programs and projects have contributed to improving its logistics infrastructure (Torres Fragoso, 2017).

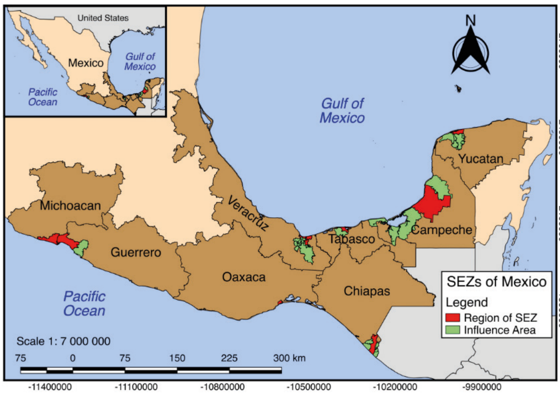

Figure 1: Special Economic Zones in Mexico.

In Table 3 we present the municipalities that belong to the Isthmus of Tehuantepec with their corresponding population and corn production (thousands of *tn*). The ID, name, and population are presented in the first, second, and third columns, respectively. The fourth column shows the corn production in thousands of *tn*, and the fifth column is the corn production that the municipality can send to the SEZ in thousands of *tn* (Municipalities with value = 0 mean that all their corn production is consumed by themselves, and they cannot send corn to the SEZ). The first 41 municipalities belong to Oaxaca and the last 19 to Veracruz.

Table 4 presents information about the distance in *km* and travel time in *min* from a municipality to a SEZ (Salina Cruz or Coatzacoalcos). The first column is the ID of the municipality. The second column shows the municipality. Third and fourth columns present the distance from a municipality to Salina Cruz and Coatzacoalcos, respectively. Fifth and sixth columns show the travel time from a municipality to Salina Cruz and Coatzacoalcos.

RESULTS AND DISCUSSION

In this section, we empirically show that results of the bi-objective formulation are efficient to solve real-life instances. We show a comparison between the special economic zones and the influence area established by the Mexican government against the solutions obtained by our BILP formulation. To test the model, we use information about the agro-industry sector, for the grinding of grains and seeds, more specifically for the corn production (*zea mays*). But the model can works for any productive vocation defined in Table 2.

To solve the bi-objective mathematical formulation we use GAMS 24.3.3 and the experimental results were carried out on a computer equipped with 8 GB of RAM and a processor Intel Core 2 Duo running @ 2.4GHz. All the instances were solved in less than one second.

Table 5 shows the experimental results of the BILP formulation by using the *Є-constraint* method with the SEZ of Salina Cruz and Coatzacoalcos. The first column is the *Є-value*, which indicates the upper bound for the second objective (maximum number of municipalities for the SEZ). The second and fourth columns show the maximum of corn production obtained in each SEZ (thousands of *tn*). The third and fifth columns present the ID of the municipalities that belong to each SEZ (see Table 3).

The corn production and the number of municipalities are different for each SEZ. The BILP incorporates a maximum of 14 municipalities for the SEZ of Salina Cruz and a maximum of 8 for Coatzacoalcos (according to the pa rameters of distance, time, and demand). However, the corn production for Coatzacoalcos is bigger than Salina Cruz. Furthermore, with Table 5, we empirically prove that minimizing the number of municipalities and maximizing the corn production for each SEZ are conflicting objectives.

Figure 2 shows the exact Pareto front for the SEZ of Salina Cruz and Coatzacoalcos, respectively. The *x*-axis shows the $\epsilon_{\text{-value}}$ (maximum number of municipalities for each SEZ) and the *y*-axis presents the optimal corn production (thousands of *tn*). At this point, we increase the $\epsilon_{\text{-value}}$ one by one until the model was infeasible (there do not exist more municipalities that satisfy the parameters fixed previously). Once the Pareto front has been obtained, the next step for the decision-maker consists in choosing the solution that satisfies the requirements given by the government.

For each SEZ, Table 6 gives a comparison of the influence area given by the Mexican government against the obtained by our BILP formulation (considering the same number of municipalities). For each one, the corn production (second and third columns), municipalities (fourth and fifth columns), and population (sixth and seventh columns) were considered. For the influence area of Coatzacoalcos, the number of municipalities established by the BILP is minor than given by the Mexican government. Also, the last row of each SEZ shows the per capita production (in thousands of *tn*) for each region. In both cases, the BILP model improves the corn production obtained by the configuration given by the government.

In Figs. 3 and 4 we present a visual comparison about the influence area for each SEZ of Salina Cruz y Coatzacoalcos, respectively. The left-hand figure corresponds to the delineation given by the Mexican government, while the right-hand figure shows the delineation obtained by our BILP formulation.

The configuration for each SEZ can change according to the productive vocation, e.g., Fig. 5 presents the configuration for sorghum production. The left-hand side is

ID	Municipality	Population	Corn production (thousands of *tn*)	Corn to send (thousands of *tn*)
1	Matías Romero Avendaño	39828	3077.00	0.00
2	San Juan Guichicovi	29364	11785.70	8270.24
3	Santo Domingo Petapa	9157	1319.30	223.02
4	Santa María Guienagati	3168	1347.50	968.23
5	Guevea de Humboldt	5409	1131.05	483.48
6	Santiago Lachiguiri	4886	1997.77	1412.82
7	Santa María Totolapilla	839	457.50	357.05
8	Santa María Jalapa del Marqués	13148	2339.42	765.34
9	Magdalena Tequisistlán	6038	1303.48	580.61
10	San Pedro Huamelula	10014	2938.86	1739.98
11	Santiago Astata	3708	327.82	0.00
12	San Miguel Tenango	729	377.72	290.44
13	Santo Domingo Tehuantepec	64639	5890.30	0.00
14	Santa María Mixtequilla	4555	830.52	285.20
15	Magdalena Tlacotepec	1220	729.50	583.44
16	Santiago Laollaga	3326	1653.26	1255.07
17	Santo Domingo Chihuitán	1486	1207.40	1029.50
18	San Pedro Comitancillo	4234	767.70	260.81
19	San Pedro Huilotepec	3146	1268.07	891.43
20	Salina Cruz	89211	289.90	0.00
21	San Blas Atempa	18406	7125.80	4922.23
22	Santa María Petapa	16518	1629.30	0.00
23	El Barrio de la Soledad	14277	1148.40	0.00
24	Ciudad Ixtepec	28637	2233.69	0.00
25	Asunción Ixtaltepec	15105	2697.93	889.56
26	El Espinal	8575	628.80	0.00
27	Santa María Xadani	8795	1384.10	331.16
28	Heróica Ciudad de Juchitán de Zaragoza	98043	8924.05	0.00
29	San Mateo del Mar	14835	451.86	0.00
30	San Dionisio del Mar	5127	592.00	0.00
31	Unión Hidalgo	15347	656.51	0.00
32	Santo Domingo Ingenio	7965	725.97	0.00
33	San Miguel Chimalapa	6817	2545.86	1729.73
34	Santa María Chimalapa	9078	1323.20	236.38
35	Santiago Niltepec	5327	1701.23	1063.48
36	San Francisco Ixhuatán	8980	2172.97	1097.88
37	San Francisco del Mar	7650	1316.00	400.14
38	Reforma de Pineda	2723	1430.07	1104.07
39	Santo Domingo Zanatepec	12161	5281.61	3825.70
40	San Pedro Tapanatepec	15152	3579.10	1765.10
41	Chahuites	11413	879.13	0.00
42	Coatzacoalcos	319187	1868.70	0.00
43	Cosoleacaque	129527	4633.00	0.00

44	Oteapán	16222	1039.50	0.00
45	Zaragoza	11354	858.50	0.00
46	Jáltipan	41644	14724.00	9738.38
47	Texistepec	20887	28489.50	25988.91
48	Oluta	16710	839.00	0.00
49	Sayula de Alemán	32721	10843.00	6925.64
50	San Juan Evangelista	33929	25381.85	21319.87
51	Jesús Carranza	29413	15037.98	11516.66
52	Hidalgotitlán	19587	29270.00	26925.04
53	Uxpanapa	29434	21859.00	18335.16
54	Nanchital de Lázaro Cárdenas del Río	30039	590.30	0.00
55	Ixhuatlán del Sureste	15800	1062.75	0.00
56	Moloacán	17504	1715.10	0.00
57	Agua Dulce	48091	1881.00	0.00
58	Minatitlán	157393	41745.00	22901.91
59	Las Choapas	81827	46737.00	36940.67
60	Chinameca	16241	3735.50	1791.13

Table 3. Population in the municipalities of the Isthmus of Tehuantepec

ID	Municipality	Distance (*km*)		Travel Time (*min*)	
		Salina Cruz	Coatzacoalcos	Salina Cruz	Coatzacoalcos
1	Matías Romero Avendaño	129	198	101	190
2	San Juan Guichicovi	159	191	135	189
3	Santo Domingo Petapa	135	217	117	221
4	Santa María Guienagati	108	302	107	295
5	Guevea de Humboldt	117	312	118	306
6	Santiago Lachiguiri	95.1	328	83	293
7	Santa María Totolapilla	113	368	140	363
8	Santa María Jalapa del Marqués	59.2	314	46	269
9	Magdalena Tequisistlán	78.9	334	66	289
10	San Pedro Huamelula	76.8	377	73	323
11	Santiago Astata	72.4	373	63	313
12	San Miguel Tenango	84.1	339	118	341
13	Santo Domingo Tehuantepec	17	293	27	255
14	Santa María Mixtequilla	41.7	284	34	250
15	Magdalena Tlacotepec	87.9	283	70	258
16	Santiago Laollaga	75	270	59	247
17	Santo Domingo Chihuitán	70.1	265	51	239
18	San Pedro Comitancillo	47.5	276	71	268
19	San Pedro Huilotepec	10.8	312	25	278
20	Salina Cruz	0	323	0	262
21	San Blas Atempa	19.9	281	37	264
22	Santa María Petapa	132	214	112	216

23	El Barrio de la Soledad	130	212	105	209
24	Ciudad Ixtepec	79.5	256	64	244
25	Asunción Ixtaltepec	52.9	266	63	254
26	El Espinal	49.1	259	62	244
27	Santa María Xadani	52.1	265	64	255
28	Heróica Ciudad de Juchitán de Zaragoza	45.1	256	58	239
29	San Mateo del Mar	30.3	332	52	305
30	San Dionisio del Mar	89.5	283	111	281
31	Unión Hidalgo	68.2	260	80	243
32	Santo Domingo Ingenio	108	257	74	235
33	San Miguel Chimalapa	125	274	110	270
34	Santa María Chimalapa	155	272	140	276
35	Santiago Niltepec	124	273	85	245
36	San Francisco Ixhuatán	164	313	120	280
37	San Francisco del Mar	163	311	132	290
38	Reforma de Pineda	157	306	108	269
39	Santo Domingo Zanatepec	154	303	103	264
40	San Pedro Tapanatepec	176	351	121	263
41	Chahuites	187	365	131	271
42	Coatzacoalcos	322	0	271	0
43	Cosoleacaque	303	31.1	254	38
44	Oteapán	306	34.7	265	48
45	Zaragoza	308	36.1	266	49
46	Jáltipan	285	40.1	253	51
47	Texistepec	281	59.3	246	80
48	Oluta	265	72.1	232	67
49	Sayula de Alemán	255	68.2	216	61
50	San Juan Evangelista	256	89.1	229	83
51	Jesús Carranza	202	132	169	119
52	Hidalgotitlán	298	59.6	304	97
53	Uxpanapa	258	170	296	251
54	Nanchital de Lázaro Cárdenas del Río	324	14.8	275	30
55	Ixhuatlán del Sureste	321	33.7	265	38
56	Moloacán	335	31.1	280	50
57	Agua Dulce	362	50.1	304	68
58	Minatitlán	306	21.6	255	28
59	Las Choapas	366	53.6	302	66
60	Chinameca	292.9	37.5	256	55

Table 4 Information of *distance* and *time* betwen municipalities.

Є-value (municipalities)	Salina Cruz		Coatzacoalcos	
	Production (thousands of *tn*)	ID of Municipalities	Production (thousands of *tn*)	ID of Municipalities
1	4922.23	21	36940.67	59
2	6662.22	10, 21	63865.72	52, 59
3	8075.04	6, 10, 21	89854.62	47, 52, 59
4	9330.11	6, 10, 16, 21	112756.53	47, 52, 58, 59
5	10359.60	6, 10, 16, 17, 21	134076.40	47, 50, 52, 58, 59
6	11251.03	6, 10, 16, 17, 19, 21	143814.78	46, 47, 50, 52, 58, 59
7	12140.59	6, 10, 16, 17, 19, 21, 25	150740.43	46, 47, 49, 50, 52, 58, 59
8	12905.93	6, 8, 10, 16, 17, 19, 21, 25	152531.55	46, 47, 49, 50, 52, 58, 59, 60
9	13489.38	6, 8, 10, 15, 16, 17, 19, 21, 25		
10	14069.99	6, 8, 9, 10, 15, 16, 17, 19, 21, 25		
11	14401.15	6, 8, 9, 10, 15, 16, 17, 19, 21, 25, 27		
12	14691.59	6, 8, 9, 10, 12, 15, 16, 17, 19, 21, 25, 27		
13	14976.79	6, 8, 9, 10, 12, 14, 15, 16, 17, 19, 21, 25, 27		
14	15237.59	6, 8, 9, 10, 12, 14, 15, 16, 17, 18, 19, 21, 25, 27		

Table 5 Results for the SEZ of Salina Cruz, Oaxaca and Coatzacoalcos, Veracruz

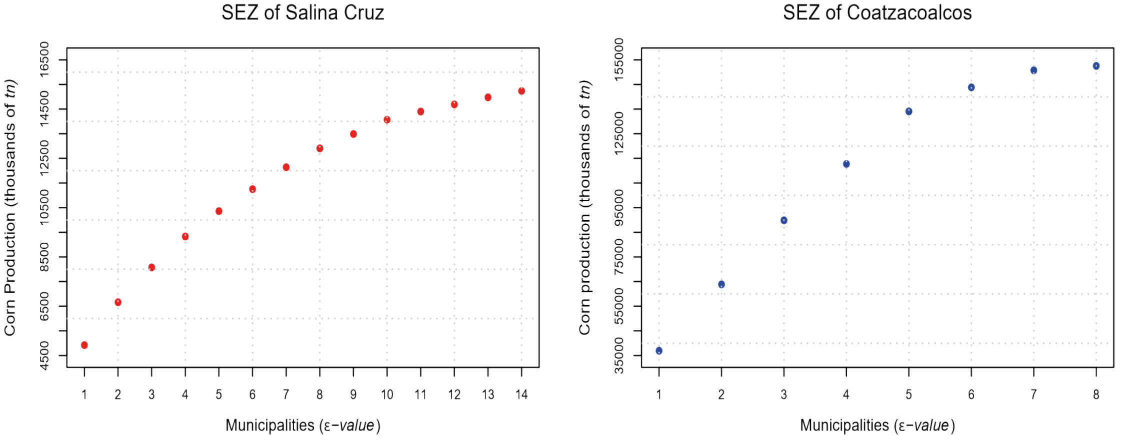

Figure 2: Pareto front for the SEZ of Salina Cruz, Oaxaca, and Coatzacoalcos, Veracruz

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SEZ	Corn Production (thousands of *tn*)		Municiaplities		Population (hab)	
	Government	BILP model	Government	BILP model	Government	BILP model
Salina Cruz	0	4922.23	Salina Cruz	San Blas Atempa	89211	18406
	Per capita production (thousands of tn/hab)				0	0.267
Coatzacoalcos	34431.42	152531.55	Coatzacoalcos Zaragoza Ixhuatlan del Sureste Minatitlan Cosoleacaque Oteapan Chinameca Jaltipan Nanchital Cardenas del Río	Chinameca Hidalgotitlan Las Choapas Minatitlan Sayula de Aleman San Juan Evangelista Texistepec Jaltipan	737407	404229
	Per capita production (thousands of tn/hab)				0.047	0.377

Table 6 Comparison of the influence area for the SEZ of Salina Cruz: Government vs BILP model

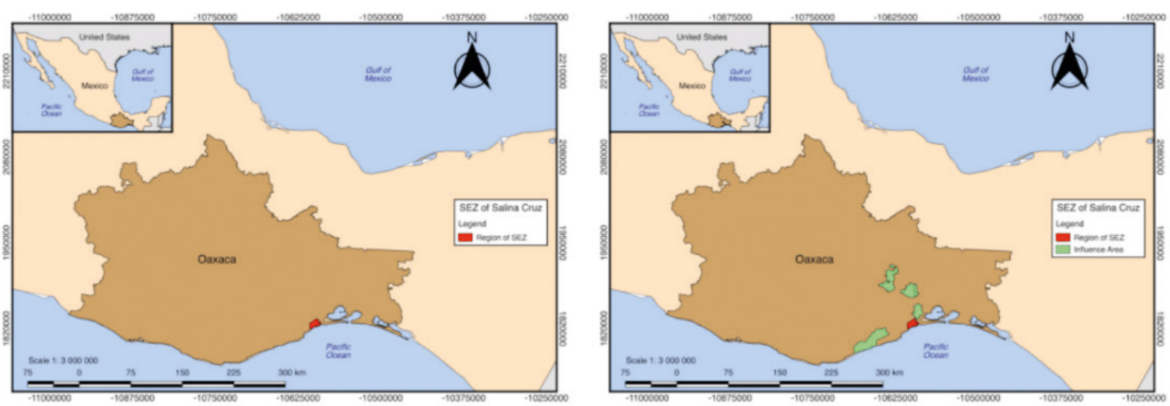

Figure 3: SEZ of Salina Cruz, Oaxaca. The left-hand figure corresponds to the delineation given by the Mexican government, while the right-hand figure shows the delineation obtained by our BILP formulation.

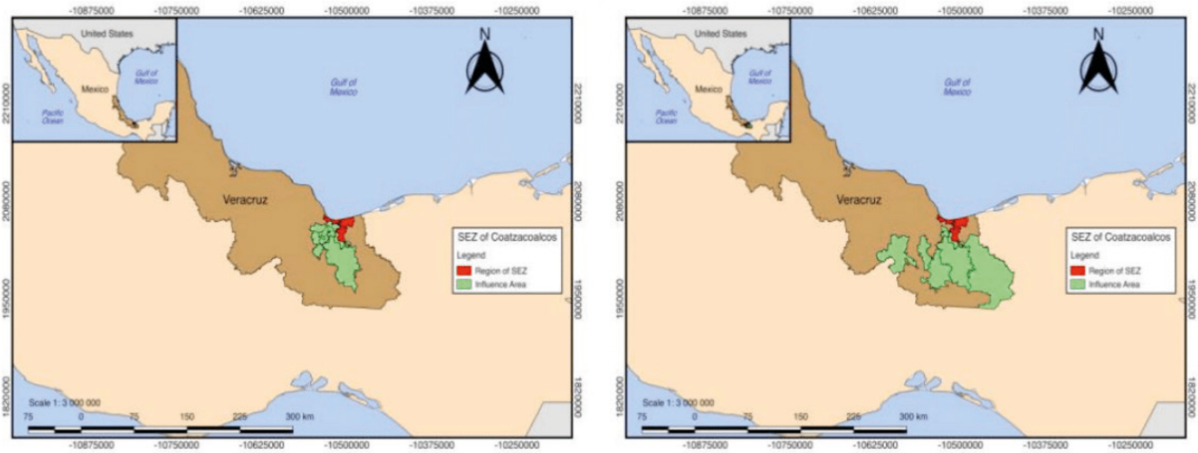

Figure 4: SEZ of Coatzacoalcos, Veracruz. The left-hand figure corresponds to the delineation given by the Mexican government, while the right-hand figure shows the delineation obtained by our BILP formulation.

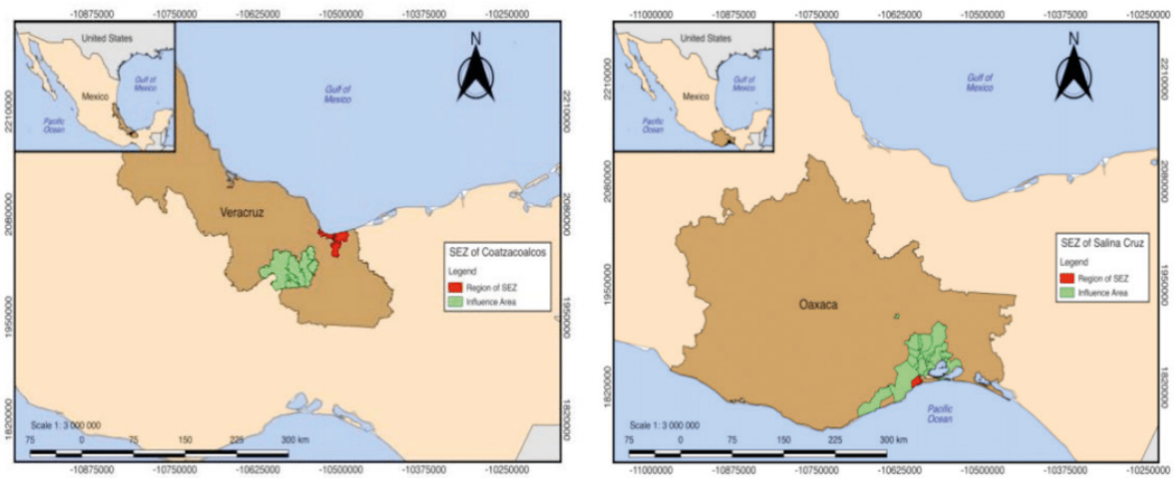

Figure 5: SEZ of Coatzacoalcos, Veracruz. Configuration for the SEZ using the sorghum production as productive vocation. The image of the left-hand side corresponds for Coatzacoalcos and the right-hand side for Salina Cruz.

for Coatzacoalcos and the right-hand side for Salina Cruz. Notice the configuration for the SEZ is different with respect to the corn production.

CONCLUSIONS

The Special Economic Zones (SEZ) have been used as a strategy to detonate regional development throughout the world. The World Bank, the Interamerican Development Bank, and Local Governments are the leading promoters of this type of initiative. The location of the SEZ is determined mainly by geographical advantages and by their capacity to attract more foreign direct investment that helps to host country to increase the region's competitiveness. Behind the SEZ, there are mainly lobbying processes between the different levels of government within the countries. Of course, the pre-existing infrastructure coupled with internal negotiations, fiscal incentives, and other facilities, provided by local governments, are critical factors for their success, especially when the local population accepts and adopts them.

In the case of Mexico, the process has been different. The federal government issued a Law for the creation of SEZ, where were established some requirements to promote regional development in the south-southeast of the country. The Law obliges to establish a priori the productive vocations and the influence area of the SEZ from its creation proposal. However, determining the influence area in a Special Economic Zone can be a hard task for the decision-makers due to the great amount of information that must be considered, e.g., the productive vocation of the region, infrastructure, population, distance and time to the SEZ. In this work, we present a new methodology based on a bi-objective mathematical formulation of integer linear programming (BILP) to determine the influence area in a Special Economic Zone. The BILP formulation is solved using the ϵ-*constraint* method, where the first objective maximizes the production of the SEZ according to a specific productive vocation (previously selected). The second objective minimizes the number of municipalities in the influence area of the SEZ.

To solve the BILP with the ϵ-*constraint* method, we add the second objective as a constraint in the mathematical formulation and fix a maximum of municipalities for the SEZ (parameter ϵ). Experimental results applied to the region of the Isthmus of Tehuantepec, Mexico, empirically show the BILP formulation is efficient and practical to delineate the influence area in a Special Economic Zone. The optimal Pareto front is obtained in seconds, considering the information about the agro-industry sector, specifically for corn production.

Also, we present a comparison of the SEZ and the influence area established by the Mexican government and the results obtained by our mathematical formulation. The solution of the BILP model improves the configuration established by the Mexican government, considering the amount of production in the SEZ and the number of municipalities in its influence area.

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