Article

Transportation model for the distribution of cocoa in Mexico

Samuel Rivera López[1]
Maricruz Gutiérrez Hernández[2]
Francisco Pérez Soto[3]

[1]Chapingo Autonomous University. Avenida Úrsulo Galván, 7B, Colonia Salitrería, Texcoco de Mora, State of Mexico, Mexico. CP. 56150. Tel. 01 (275) 1095016. (sriveral_comercio@hotmail.com). [2]Chapingo Autonomous University. Florida Street 67, Colonia El Arenal, Zacualtipán de Ángeles, Hidalgo, Mexico. CP. 43200. Tel. 01(556) 1724351. (maricruzgutt@hotmail.com). [3]Division of Economic-Administrative Sciences-Chapingo Autonomous University. Mexico-Texcoco Highway km 38.5, Chapingo, Mexico. CP. 56230.

[§]Corresponding author: perezsotofco@gmail.com.

Abstract

Cocoa is a product originating in Mexico whose production does not meet domestic demand, so there is a need to import much of what the Mexican market consumes, therefore, it is of great importance to distribute optimally the quantities produced internally with the purpose of minimizing the transportation costs of the grain. The objective of the research was to formulate a transport model that optimizes the distribution of cocoa in Mexico, minimizing the cost of transportation, both for a closed economy and for an open economy. Linear programming was used to solve the transport problem, since it allows determining the optimal way to transfer goods, minimizing total distribution costs. The main results show that the national apparent consumption, in 2015, was 51 394.13 t, the apparent per capita consumption of cocoa in the country was 0.43 kg. The states that can see totally satisfied their demand for cocoa, only with the surplus of state production of Tabasco and Chiapas, are: Guerrero, Oaxaca, Querétaro, Quintana Roo, Tamaulipas, Veracruz, Campeche, Mexico City, Hidalgo, State of Mexico, Morelos, Puebla, Tlaxcala and Yucatán, while Michoacán can obtain 14 of the 65 trucks it demands. The above, leads to a minimization of transportation costs, this being $9 500 068.00. In order to meet the national demand for cocoa, two ports of entry for this crop were considered and the minimum transportation cost was $18 123 640.00.

Keywords: closed economy, import logistics, linear programming, open economy.

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Introduction

Cocoa (*Theobroma cacao*) is a culture native to Mexico, of cultural importance for the country, so there is a general statement of protection of the appellation of origin of the 'Cacao Grijalva' that protects green or roasted/ground cocoa of the species in mention that takes place in the Grijalva Region of Tabasco, this one is integrated by three productive subregions: Chontalpa, Mountain range and Center and they group 11 municipalities of Tabasco (DOF, 2016). The tropical region of America presents the optimal conditions for the cultivation of cocoa, so in these areas it has been cultivated for about three thousand years by the Olmec culture; however, the Maya are attributed the spreading of the grain when they use it, even as a currency in their barter system (Nisao, 2007).

The peoples of Mesoamerica gave a great deal of sentimental value to cocoa since they considered it a gift from the gods; in fact, *Theobroma* in Greek means 'food of the gods', the fruit symbolized the human heart and chocolate contained blood; currently, cocoa and its derivatives have a prominent role in international markets, especially in agro-industry (Salas and Hernández, 2015). In 2017, according to the Agri-Food and Fisheries Information Service (SIAP), in Mexico, 27 287.25 t of cocoa were produced, the producing states of this grain were: Tabasco with 17 430 21 t harvested, Chiapas with 9 611 63 t and Guerrero with 245 41 t (SIAP, 2018).

It should be noted that the production of cocoa in Mexico is in the hands of 37 thousand producers, approximately, Tabasco includes 68% of these, Chiapas has 31% of them and Guerrero has about 1% remaining (Orozco, 2018).

"The 80% of world production is concentrated in cocoas: outsiders or ordinary, trinitario and creole and Mexico has all three types and promotes the increase of creole cocoas, since it is the country of origin" (Jaramillo, 2017). However, in terms of cocoa production, "the socioeconomic and parasitological factors that limit production in a precise and precise manner have not been identified in Mexico and everything points to the fact that diseases contribute significantly to the disappearance of this important crop" (Hernández *et al*., 2015), given that the import of this grain is essential to meet domestic demand. In 2017, 41 321 97 t of cocoa were imported from around the world, the main suppliers were: Ecuador with 27 012 64 t, Ivory Coast with 9 076 7 t, Colombia with 3 022 33 t, Peru with 1 350 98 t and Republic Dominican Republic with 840.63 t (SIAVI, 2018).

The objective of the work was to state a transport model that optimizes the distribution of cocoa in Mexico, minimizing the cost of transportation. The hypothesis was that the national production of cocoa could only supply the demand of the southern states of the country, given the geographical proximity they have with respect to the producing states, while the states of the center-north of the country would depend on the imports of cocoa to see your demand satisfied. Imports have been gaining more weight in the consumption of national cocoa, mainly due to the growing demand of large chocolate companies that fail to meet their requirements in the domestic market due to the scarce national production of grain (Andrade, 2017). Therefore, in a complementary manner, a minimum cost transport model for an open economy was developed.

Materials and methods

Within the applications of linear programming highlights the problem of transport whose purpose is to determine the optimal way to move goods, since “transportation generally represents the single most important element in logistics costs for most companies. It has been observed that cargo movement absorbs between one and two thirds of total logistics costs” (Quintero *et al*., 2016). It should be noted that “the general problem of transport -refers literally or figuratively- to the distribution of any goods from any group of supply centers, called origins, to any group of reception centers, called destinations, in such a way that the total distribution costs are minimized” (Hillier and Lieberman, 2010).

In general, the origin O_i (i= 1, 2, 3,…, n) has Xi units to offer and the destination D_j (j= 1, 2, 3,…, n) has a demand of X_j units. In the case of Mexican cocoa, there are two origins in a closed economy and 30 destinations. In some applications, the quantities of supply or resources and of demand have integer values, and when working with the model it will be required that the quantities distributed take integer values; it should be noted that the entire programming is a problem of linear programming in which it is required that some or all of the variables adopt non-negative integer values (Winston, 2005).

The property of whole solutions establishes that for transport problems in which X_i and X_j have an integer value, all the basic variables (assignments), in all the feasible basic solution (including the optimal one), also have integer values. For its part, ownership of feasible solutions establishes that a necessary and sufficient condition for a transportation problem to have feasible solutions is that (Hillier and Lieberman, 2010).

$$\sum_{i=1}^{n} X_i = \sum_{j=1}^{n} X_j$$

This property can be verified by observing that the restrictions require that.

$$\sum_{i=1}^{n} X_i \ \ y \sum_{j=1}^{n} X_j = \sum_{i=1}^{n} . \sum_{j=1}^{n} X_{ij}$$

The condition that the total resources must equal the total demand requires that the system be balanced, if the problem has some physical meaning and this condition is not met, it would imply that X_i, or X_j, represent a dimension and not an exact requirement. In this case, an imaginary or fictitious origin or destination can be introduced to capture the slack, in order to convert the inequalities into equalities and satisfy the feasibility condition (Hillier and Lieberman, 2010). In this sense, given that cocoa production in Mexico does not satisfy domestic demand, it is necessary to import this product, so, for the open economy model, two fictitious origins were added, Jalisco and Yucatán.

To determine which states of Mexico are deficit or surplus in the consumption of cocoa, the apparent national consumption was calculated, the result was divided among the national population to obtain the apparent consumption per capita. The data obtained was multiplied by the population of each state and its consumption was estimated. The production minus the demand for this grain determined whether the state is a supplying or demanding cocoa. The formulas used were the following (Miranda, 2005).

$$\text{Apparent national consumption} = \text{production} + \text{import} - \text{export}$$

Where: national apparent consumption= is the quantity demanded of cocoa in tons by the Mexican market; production= it refers to the amount of cocoa harvested in Mexico in tons, the data was consulted in the Agri-Food and Fisheries Information Service (SIAP), the year of study was 2015; import= it is the imported quantity of cocoa expressed in tons, tariff item 18010001 “Cocoa beans, whole or split, raw or roasted” was used. The data was consulted in the Internet Tariff Information System (SIAVI) for the year 2015; export= it is the quantity exported of cocoa expressed in tons; tariff item 18010001 “cocoa beans, whole or split, raw or roasted” was used. The data was consulted in the SIAVI for the year 2015.

$$\text{Apparent consumption per capita} = \frac{\text{Apparent consumption}}{\text{National population}}$$

Where: apparent consumption per capita= it is the quantity demanded of cocoa for each person in Mexico; National population= express the number of inhabitants in Mexico in 2015, the data was consulted in the National Institute of Statistics and Geography (INEGI).

$$\text{State consumption} = \text{apparent consumption per capita} * \text{state population}$$

State population= is the number of inhabitants in each of the states of Mexico in 2015, the data was consulted in the INEGI.

The transportation costs were estimated from the trial version of the GlobalMap Software “roads of road transportation of Mexico 2018”. They were calculated for a type T3-C2 transport that, according to NOM-012-SCT-2-2017, has a capacity of 30 t (DOF, 2017). Therefore, the deficit or surplus quantities used in the model are presented in truck units.

The origin (O_i) states were those whose production was greater with respect to their consumption; that is, those that had a surplus, while the destination states (D_j) were those that presented a deficit. Origins were taken as the larger cities near the area of production of each state, while destinations for state capitals were used, considering that the bulk of economic activity, mostly concentrated in them.

The variable X11 corresponds to the origin ‘Chiapas’ and destination ‘Aguascalientes’, the variable X12 belongs to the origin ‘Chiapas’ and destination ‘Baja California’, ..., the variable X130 belongs to the origin ‘Chiapas’ and destination ‘Zacatecas’. For its part, the variable representing the origin ‘Tabasco’ and destination ‘Aguascalientes’ is X21, ..., and the origin ‘Tabasco’ and destination ‘Zacatecas’ is X230.

For the open economy, two fictitious origins were used: Jalisco and Yucatán, initiating their variables with X3 and X4, respectively.

Model for a closed economy

Objective function
MIN
22282X11+49509X12+51168X13+11251X14+34585X15+15348X16+24842X17+25499X18+26931X19+20120X110+18263X111+15362X112+22842X113+16381X114+19493X115+15934X116+26495X117+25739X118+6757X119+13456X120+18042X121+10104X122+20197X123+33333X124+41904X125+18344X126+13872X127+11987X128+12903X129+23480X130+17745X21+44647X22+46554X23+4691X24+30061X25+10486X26+19980X27+20965X28+22068X29+15586X210+13726X211+10502X212+18303X213+11518X214+14923X215+11071X216+21633X217+20880X218+6648X219+8591X220+13500X221+5783X222+15660X223+28796X224+37046X225+13809X226+9010X227+7129X228+6346X229+18946X230.

Offer restrictions
X11+X12+X13+X14+X15+X16+X17+X18+X19+X110+X111+X112+X113+X114+X115+X116+X117+X118+X119+X120+X121+X122+X123+X124+X125+X126+X127+X128+X129+X130=270
X21+X22+X23+X24+X25+X26+X27+X28+X29+X210+X211+X212+X213+X214+X215+X216+X217+X218+X219+X220+X221+X222+X223+X224+X225+X226+X227+X228+X229+X230=578.

Demand constraints
X11+X21<=18
X12+X22<=47
X13+X23<=10
X14+X24<=12
X15+X25<=10
X16+X26<=74
X17+X27<=50
X18+X28<=128
X19+X29<=25
X110+X210<=83
X111+X211<=43
X112+X212<=40
X113+X213<=112
X114+X214<=231
X115+X215<=65
X116+X216<=27
X117+X217<=16
X118+X218<=73
X119+X219<=56
X120+X220<=88
X121+X221<=29
X122+X222<=21

X123+X223<=38
X124+X224<=42
X125+X225<=41
X126+X226<=49
X127+X227<=18
X128+X228<=116
X129+X229<=30
X130+X230<=22.

Model for an open economy
Objective Function
MIN
22282X11+49509X12+51168X13+11251X14+34585X15+15348X16+24842X17+25499X18+26931X19+20120X110+18263X111+15362X112+22842X113+16381X114+19493X115+15934X116+26495X117+25739X118+6757X119+13456X120+18042X121+10104X122+20197X123+33333X124+41904X125+18344X126+13872X127+11987X128+12903X129+23480X130+17745X21+44647X22+46554X23+4691X24+30061X25+10486X26+19980X27+20965X28+22068X29+15586X210+13726X211+10502X212+18303X213+11518X214+14923X215+11071X216+21633X217+20880X218+6648X219+8591X220+13500X221+5783X222+15660X223+28796X224+37046X225+13809X226+9010X227+7129X228+6346X229+18946X230+9530X31+31437X32+33336X33+24273X34+21846X35+9478X36+14564X37+3244X38+14153X39+7366X310+5352X311+9190X312+6766X313+8086X314+4436X315+9472X316+8424X317+15466X318+15561X319+11196X320+7824X321+25551X322+10491X323+15590X324+24161X325+13522X326+10828X327+12483X328+26412X329+10731X330+24749X41+51651X42+53553X43+2149X44+37065X45+17491X46+26984X47+27966X48+29073X49+22260X410+20405X411+17504X412+25307X413+18520X414+21602X415+18076X416+28637X417+27886X418+13652X419+15596X420+20179X421+4123X422+22664X423+35475X424+44046X425+20813X426+16017X427+14130X428+534X429+25947X430.

Offer restrictions
X11+X12+X13+X14+X15+X16+X17+X18+X19+X110+X111+X112+X113+X114+X115+X116+X117+X118+X119+X120+X121+X122+X123+X124+X125+X126+X127+X128+X129+X130=270
X21+X22+X23+X24+X25+X26+X27+X28+X29+X210+X211+X212+X213+X214+X215+X216+X217+X218+X219+X220+X221+X222+X223+X224+X225+X226+X227+X228+X229+X230=578
X31+X41+X32+X42+X33+X43+X34+X44+X35+X45+X36+X46+X37+X47+X38+X48+X39+X49+X310+X410+X311+X411+X312+X412+X313+X413+X314+X414+X315+X415+X316+X416+X317+X417+X318+X418+X319+X419+X320+X420+X321+X421+X322+X422+X323+X423+X324+X424+X325+X425+X326+X426+X327+X427+X328+X428+X329+X429+X330+X430=766.

Demand constraints
X11+X21+X31+X41=18
X12+X22+X32+X42=47
X13+X23+X33+X43=10
X14+X24+X34+X44=12

X15+X25+X35+X45=10
X16+X26+X36+X46=74
X17+X27+X37+X47=50
X18+X28+X38+X48=128
X19+X29+X39+X49=25
X110+X210+X310+X410=83
X111+X211+X311+X411=43
X112+X212+X312+X412=40
X113+X213+X313+X413=112
X114+X214+X314+X414=231
X115+X215+X315+X415=65
X116+X216+X316+X416=27
X117+X217+X317+X417=16
X118+X218+X318+X418=73
X119+X219+X319+X419=56
X120+X220+X320+X420=88
X121+X221+X321+X421=29
X122+X222+X322+X422=21
X123+X223+X323+X423=38
X124+X224+X324+X424=42
X125+X225+X325+X425=41
X126+X226+X326+X426=49
X127+X227+X327+X427=18
X128+X228+X328+X428=116
X129+X229+X329+X429=30
X130+X230+X330+X430=22.

Once the objective function and the respective supply and demand restrictions for each of the models were proposed, they were resolved using the Linear, Interactive, and Discrete Optimizer package (Lindo).

Results and discussion

In 2015, the national production of cocoa in Mexico was 28 006.59 t (SIAP, 2018), exports were of 133.83 t and imports totaled 23 521.37 t (SIAVI, 2018), so the national apparent consumption was 51 394.13 t. The total population of Mexico, in that year, was 119 938 472 inhabitants (INEGI, 2018), therefore, the apparent per capita consumption of cocoa in the country was 0.43 kg, this figure coincides with that presented in the Agroalimentary Atlas 2016 of the SIAP (SAGARPA, 2016).

Given that cocoa, in 2015, was only produced in the states of Tabasco, Chiapas and Guerrero, and in the latter the production was not enough to supply the state consumption of this crop, they are considered as national supplying states only to Tabasco and Chiapas, with a volume of 17 363.57 and 7 143.91 t respectively, once their domestic demand has been met. Table 1 shows the calculation of the deficit or surplus of cocoa of each state in tons of product, also has a column that was called equivalence that refers to the number of trucks that supply or demand each state. The total amount of trucks in surplus was 848, while in deficit were 1 614 trucks, so it was necessary to import 766 trucks to fulfill the feasible solution property in programming.

Table 1. Classification of states (demandant and suppliers).

Key	State	Production (t)	Consumption (t)	Deficit (t)	Superavit (t)	Equivalence (truck)
D1	Aguascalientes	0	563.93	563.93	-	18
D2	Baja California	0	1 435.02	1 435.02	-	47
D3	Baja California Sur	0	307.83	307.83	-	10
D4	Campeche	0	386.62	386.62	-	12
O1	Chiapas	9 387.43	1 269.1	-	8 118.33	270
D5	Chihuahua	0	306.42	306.42	-	10
D6	Ciudad de Mexico	0	2 240.52	2 240.52	-	74
D7	Coahuila de Zaragoza	0	1 529.54	1 529.54	-	50
D8	Colima	0	3 850.25	3 850.25	-	128
D9	Durango	0	754.1	754.1	-	25
D10	Guanajuato	0	2 513.08	2 513.08	-	83
D11	Guerrero	225.71	1 517.85	1 292.14	-	43
D12	Hidalgo	0	1 226.79	1 226.79	-	40
D13	Jalisco	0	3 376.84	3 376.84	-	112
D14	Mexico	0	6 952.65	6 952.65	-	231
D15	Michoacán	0	1 970.73	1 970.73	-	65
D16	Morelos	0	819.39	819.39	-	27
D17	Nayarit	0	509.35	509.35	-	16
D18	Nuevo León	0	2 199.06	2 199.06	-	73
D19	Oaxaca	0	1 703.86	1 703.86	-	56
D20	Puebla	0	2 649.58	2 649.58	-	88
D21	Querétaro	0	875.8	875.8	-	29
D22	Quintana Roo	0	645.24	645.24	-	21
D23	San Luis Potosí	0	1 167.15	1 167.15	-	38
D24	Sinaloa	0	1 275.7	1 275.7	-	42
D25	Sonora	0	1 231.69	1 231.69	-	41
O2	Tabasco	18 393.45	1 028.82	-	17 364.63	578
D26	Tamaulipas	0	1 479.85	1 479.85	-	49
D27	Tlaxcala	0	546.01	546.01	-	18
D28	Veracruz	0	3 482.81	3 482.81	-	116
D29	Yucatán	0	900.83	900.83	-	30
D30	Zacatecas	0	677.71	677.71	-	22

Elaboration with data from the SIAP and INEGI.

Under conditions of a closed economy, production and distribution must be efficient for the country, but this does not guarantee that the entire product is consumed, in that case there is a excess of production that can be subjected to an agro-industrial process to obtain by-products; or, export it through international trade (Ayllón *et al*., 2015). In the case of cocoa, production does not supply domestic demand, therefore, international trade is also used, but in the sense of acquiring abroad the quantity of product necessary to cover domestic demand.

In the Table 2 shows the transportation costs of the two national origins, considering the place of production and two international origins, considering two possible ports of entry for international cocoa.

Table 2. Transportation costs of national and international origins.

Key	Tapachula, Chiapas O1 ($)	Villahermosa, Tabasco O2 ($)	Lázaro Cárdenas, Jalisco O3 ($)	Puerto Progreso, Yucatán O4 ($)
D1	22 282	17 745	9 530	24 749
D2	49 509	44 647	31 437	51 651
D3	51 168	46 554	33 336	53 553
D4	11 251	4 691	24 273	2 149
D5	34 585	30 061	21 846	37 065
D6	15 348	10 486	9 478	17 491
D7	24 842	19 980	14 564	26 984
D8	25 499	20 965	3 244	27 966
D9	26 931	22 068	14 153	29 073
D10	20 120	15 586	7 366	22 260
D11	18 263	13 726	5 352	20 405
D12	15 362	10,502	9 190	17 504
D13	22 842	18 303	6 766	25 307
D14	16 381	11,518	8 086	18 520
D15	19 493	14 923	4 436	21 602
D16	15 934	11 071	9 472	18 076
D17	26 495	21 633	8 424	28 637
D18	25 739	20 880	15 466	27 886
D19	6 757	6 648	15, 61	13 652
D20	13 456	8 591	11 196	15 596
D21	18 042	13 500	7 824	20 179
D22	10 104	5 783	25 551	4 123
D23	20 197	15 660	10 491	22 664
D24	33 333	28 796	15 590	35 475
D25	41 904	37 046	24 161	44 046
D26	18 344	13 809	13 522	20 813
D27	13 872	9 010	10 828	16 017
D28	11 987	7 129	12 483	14 130
D29	12 903	6 346	26 412	534
D30	23 480	18 946	10 731	25 947

Elaboration with data from GlobalMap.

The total number of trucks that must be distributed nationwide to cover the apparent demand of all states is 1 614; however, in the case of the analysis of a closed economy, the available number of trucks in Mexico in 2015 was 848, so there is a deficit of 766 trucks (Table 3). According to the results of the programming carried out to reduce the transportation costs of cocoa, considering only the national production, the value of the objective function is $9 500 068.00.

Table 3. Cocoa distribution under closed economy.

Variable	Origin	Destination	Quantity (truck)
X111	Chiapas	Guerrero	43
X115	Chiapas	Michoacán	14
X119	Chiapas	Oaxaca	56
X121	Chiapas	Querétaro	29
X122	Chiapas	Quintana Roo	21
X126	Chiapas	Tamaulipas	49
X128	Chiapas	Veracruz	58
X24	Tabasco	Campeche	12
X26	Tabasco	Mexico City	74
X212	Tabasco	Hidalgo	40
X214	Tabasco	Mexico State	231
X216	Tabasco	Morelos	27
X220	Tabasco	Puebla	88
X227	Tabasco	Tlaxcala	18
X228	Tabasco	Veracruz	58
X229	Tabasco	Yucatán	30
	Total		848

Elaboration based on the results of the Lindo program.

According to the results of the programming carried out to reduce the transportation costs of cocoa, considering an open economy, the value of the objective function is $18 123 640. Table 4 shows what the optimal distribution would be by reducing the costs of transport.

Table 4. Distribution of cocoa under open economy.

Variable	Origin	Destination	Quantity (truck)	Variable	Origin	Destination	Quantity (truck)
X119	Chiapas	Oaxaca	56	X32	Jalisco	Baja California	47
X121	Chiapas	Querétaro	29	X33	Jalisco	Baja California Sur	10
X122	Chiapas	Quintana Roo	21	X35	Jalisco	Chihuahua	10
X123	Chiapas	San Luis Potosí	38	X37	Jalisco	Coahuila de Zaragoza	50
X126	Chiapas	Tamaulipas	49	X38	Jalisco	Colima	128
X128	Chiapas	Veracruz	77	X39	Jalisco	Durango	25
X24	Tabasco	Campeche	12	X310	Jalisco	Guanajuato	83

Variable	Origin	Destination	Quantity (truck)	Variable	Origin	Destination	Quantity (truck)
X26	Tabasco	Ciudad de Mexico	74	X311	Jalisco	Guerrero	43
X212	Tabasco	Hidalgo	40	X313	Jalisco	Jalisco	112
X214	Tabasco	Estado de Mexico	231	X315	Jalisco	Michoacán	65
X216	Tabasco	Morelos	27	X317	Jalisco	Nayarit	16
X218	Tabasco	Nuevo León	49	X318	Jalisco	Nuevo León	24
X220	Tabasco	Puebla	88	X324	Jalisco	Sinaloa	42
X227	Tabasco	Tlaxcala	18	X325	Jalisco	Sonora	41
X228	Tabasco	Veracruz	39	X330	Jalisco	Zacatecas	22
X31	Jalisco	Aguascalientes	18	X429	Yucatán	Yucatán	30

Elaboration based on the results of the Lindo program.

The reduced costs show all the routes that were not selected by the model in the optimal solution, whose value is different from zero. The interpretation of these values indicated that by introducing these routes the value of the objective function would increase. For example, transporting a truck with cocoa from Chiapas to Aguascalientes (X11) would raise the value of the objective function by $2 789.00 pesos, in the same way, forcing the model to transport a cocoa truck from Chiapas to Baja California (X12) would raise the value of the objective function in $30 016.00 pesos.

Conclusions

The national production of cocoa in Mexico in 2015 was insufficient to satisfy domestic consumption, so imports of this product were made, the national apparent consumption was 51.3 thousand tons. Under the system of closed economy, it will only be able to distribute 848 trucks, so minimizing transport costs only the states of central-south of the country could fully meet their demand for this grain, while Michoacán can get 14 of the 65 truck that demand. The optimal cost of transportation with a closed economy was $9.5 million pesos.

In order to cover the national demand for cocoa, it is necessary to resort to foreign markets, which is why the port of Lazaro Cardenas, Jalisco, turned out to be a viable option, while Puerto Progreso, Yucatán was only feasible to supply the demand of its state; therefore, it is not a viable option for the importation of cocoa. The optimum cost of the market with an open economy was $18.1 million pesos.

Finally, it is recommended to carry out the transport model considering the agroindustrial demand of this crop in each state since, being a crop that is part of the chocolate production chain, the industry has great weight in the demand for it. In addition, a new model can be run considering other ports in the Gulf of Mexico.

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