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ORIGINAL ARTICLE

The Stability in Rational Composition of the Sugarcane Harvest-Transport-Reception System

La Estabilidad en la composición racional del sistema cosecha-transporte-recepción de la caña de azúcar

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ABSTRACT: The present investigation was carried out in "Héctor Molina Riaño" Base Business Unit, with the objective of determining the rational organization of the sugarcane harvest-transport-reception system, through the integration of mathematical models, which guarantee the stability of the flow in the system. The rational conformation of the harvest-transport-reception-system was determined using the following methods: linear programming, queuing theory for a single service station and for stations in cascades. When analyzing the stability of the compositions with the Markov chain model, it is found that the most stable variant is when the queuing theory is used in cascades when working in fields of 75 t/ha, with two CASE IH 8800 Harvesters and four Tractors BELARUS 1523 + four VTX 10000 dump trailers, four HOWO SINOTRUCK aggregates + two trailers and three reception centers with a probability of 53.79% that the cycle will not be interrupted and a cost of system stops of 33.05 peso/h , being possible to reduce the costs by stops in more than 30%, observing a marked influence when increasing the number of collection centers

Keywords: Organization, Queuing Theory, Markov Chain, System.

RESUMEN: La presente investigación se realizó en la Unidad Empresarial de Base Héctor Molina Riaño, con el objetivo de determinar la organización racional del sistema cosecha-transporte-recepción de la caña de azúcar, mediante la integración de modelos matemáticos, que garanticen la estabilidad del flujo del sistema. Se determinó la conformación racional de la brigada cosecha transporte empleando los métodos: programación lineal, teoría de cola para una estación única de servicio y para estaciones en cascadas. Al analizar la estabilidad de las composiciones con el modelo de cadenas de Markov se tiene que la variante más estable es cuando se emplea la teoría de colas en cascadas al trabajar en campos de 75 t/ha, con dos Cosechadoras CASE IH 8800 y cuatro Tractores BELARUS 1523 + cuatro remolques autobasculantes VTX 10000, cuatro agregados HOWO SINOTRUCK + dos remolques y tres centros de recepción con una probabilidad de 53,79% de que no se interrumpa el ciclo y un costo por paradas del sistema de 33,05 peso/h, siendo posible reducir los costos por paradas en más del 30%, observándose una marcada influencia al incrementarse el número de centros de acopio.

Palabras clave: organización, teoría de cola, cadenas de Markov.

INTRODUCTION

The agriculture of the present times demands an optimal exploitation of mechanized systems; the concentration and specialization of production and the increase in productivity at work, based on agricultural yields, the reduction of production costs, the obtaining of new varieties of plants, as well as the mechanization and scientific automation of the work (Aguilera & Fonseca, 2013).

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In the process of harvesting and transport, and specifically when talking about sugar cane, the analysis of the relation between the harvest and transport links requires the study of a waiting system in which it is necessary to balance said relationship, in such a way that the loss for these reasons is minimal. In the work of the sugarcane combine, it happens that it waits for the means of transport or the transport waits for it to receive the load, in addition to waiting at the reception center for the unloading process. As a result of the loss of time waiting in the queue, considerable material means, productive capacities and human energy are lost. This type of phenomenon is characteristic and is associated with the development of the productive forces. To eliminate queues there is a rational means: study the laws of queue formation; learn to calculate the necessary number of service units and on this basis, organize the work of the service systems (Suárez, 1999a, 1999b). For this, the application of mathematical modeling is essential in making scientifically based decisions, free from all kinds of improvisations, which allow justifying, for example, production levels, use of technical means and material resources whose combination produces the maximum efficiency.

Among the mathematical methods and models that have been used to determine the rational organization of the harvest-transport process, the following can be mentioned: the deterministic method, Markov chains, Linear Programming and the Mass Service or Queuing Theory (Rodríguez *et al*., 2015; Morejón, 2012; Fonollosa *et al*., 2002).

A deterministic model is a mathematical model where the same inputs will invariably produce the same outputs, not contemplating the existence of chance or the uncertainty principle. The inclusion of greater complexity in the relationships, with a greater number of variables and elements outside the deterministic model, will make it possible for it to approach a probabilistic model or a stochastic approach. That, applied to the subject of this research, makes possible to determine the number of means of transport for a group of harvesters, based on the productivity of these links of the harvest-transport-reception system, with the limitation that it does not consider the probabilistic nature of the interrelation between the productive links (Morejón, 2012; Rodríguez, 2007).

Markov chains, named after the Russian mathematician Andrei Andreevitch Markov (1856-1922), are a series of events, in which the probability of an event occurring depends on the immediately preceding event. Indeed, chains of this type have memory, they "remember" the last event and this determines the possibilities of future events. This dependence on the previous event distinguishes Markov chains from series of independent events (Sánchez, 2016; Ibe, 2013; Hermanns, 2002a; 2002b; Kijima, 1997).

For the analysis of the rational structure of the sugarcane harvest-transport complex using the Markov model, it is assumed that it is a stochastic process, since it varies over time in a probabilistic manner, which is nothing more than a succession of observations and the values of these cannot be predicted exactly (Hillier & Liberman, 2010).

The simplest case of a stochastic process, in which the results depend on others, occurs when the result at each stage depends only on the result of the previous stage and not on any of the previous results. Such a process is called a Markov process or Markov chain (a chain of events, each event linked to the preceding one). As mentioned before, these chains have memory, they remember the last event and this determines the possibilities of future events (Ching 2006; Bini *et al*., 2005). This just distinguishes them from a series of independent events like the act of tossing a coin. Markov chains have three basic properties:

1. The sum of the probabilities of the states must equal 1.
2. The transition matrix must be square.
3. Transition probabilities must be between 0 and 1.

For the study of the Markov chains, some key concepts must be taken into account, such as the following:

> States: The state of a system at an instant t is a variable whose values can only belong to the set of states in the system. The system modeled by the chain, therefore, is a variable that changes with the value of time, a change that is called a transition.
>
> Transition matrix: The elements of the matrix represent the probability that the next state is the one corresponding to the column if the current state is the one corresponding to the row.

Technological complexes are made up of machines and aggregates that have different levels of reliability. To achieve a high level of reliability of the complex, machines and aggregates with high level of reliability should be sought. When it is not possible to achieve, then the working capacity of the complex is maintained by introducing a higher number of machines (reserves), reducing the working regime of the machines, organizing technical maintenance and repair activities, or through the combination of these measures. It is necessary to take into account that these measures translate into an increase in the operating cost, which in turn, depends on the reliability of the complex, mainly on the number and complexity of failures and on the maintainability that is characterized by the cost of fault elimination (Amú, 2010; Bolch *et al*., 2006; Fernández & Delgado, 1989; Fernández & Álvarez, 1988; Conlisk, 1976).

MATERIALS AND METHODS

The research was carried out in "Héctor Molina Riaño" Base Business Unit, with the objective of determining the rational organization of the sugarcane harvest-transport-reception system, through the integration of mathematical models, which guarantee the stability of the system flow. Table 1 shows the agricultural yields of the evaluated fields, as well as the technical means used for harvesting and transport, specifying the load capacity of the latter, as well as the distances to be transported in total and according to the type of road.

The rational conformation of the harvest-transport-reception system was determined using the following methods: linear programming and queuing theory, for a single service station and for stations in cascades, analyzing the stability of the compositions with the Markov chain model.

The implementation of the Markov model is based on the existence of stochastic processes, which is nothing more than the succession of observations X1, X2...Xn (Rodríguez, 2019). The values of these observations cannot be predicted exactly, but the probabilities for the different possible values at any instant of time can be specified, where X1: variable that defines the initial state of the process and Xn: variable that defines the state of the process at the instant of time n.

For each possible value of the initial state *E1* and for each one of the successive values *En* of the states Xn, n = 2, 3…, it must be fulfilled that:

$$P(X_{n+1}=E_{n+1}|X_1=E_1,X_2,=E_2,\dots,X_n=E_n) \quad (1)$$

Since the Markov chain is a stochastic process in which if the current state Xn and the previous states X1, . . ., Xn-1 are known, then:

The probability of the future state Xn+1 does not depend on the previous states X1, . . ., Xn-1, and it only depends on the current state Xn. Namely:

For n = 1, 2, and for any sequence of states E1, . . . E_{n+1}

$$0n+1P(X_{n+1}=E_{n+1}|X_1=E_1,X_2,=E_2,\dots,X_n=E_n) \\ =P(X_{n+1}=E_{n+1}|X_n=E_n) \quad (2)$$

Within the Markov models, the finite Markov model is highly important for the analysis of the stability of processes in flow, since it is a chain for which there is only a finite number k of possible states E1, . , Ek and at any instant of time the chain is in one of these k states (Rodríguez, 2019).

The advantages of using the Markov chains to determine the stability of the machine complex during the sugar cane harvest are:

- It allows knowing the stability of the process from the stability of each component part of it;
- The stability of each part of the process can be modeled for conditions that would cause the process to stop;
- It is a simple and useful form of dependence between the random variables that make up the stochastic process, analyzing the transition from one state to another as a stochastic process.
- When determining the costs for stops, it takes into account the probability of system stoppage.
- The state at t + 1 only depends on the state at t and not on the previous evolution of the system

These aspects make it possible to know the probability of transition from one state to another according to Rodríguez (2019), this probability in its conditioned form, is determined by the following expression:

$$P(X_{n+1}=E_j|X_n=E_i) \quad (3)$$

In the same way, the stationary transition probability can be analyzed:

A Markov chain has stationary transition probabilities if for any pair of states Ei and Ej exists a transition probability pij such that:

$$P\left(X_{n+1}=E_j\middle|X_n=E_i\right)=p_{ij}\text{para } n=1, 2, \dots. \quad (4)$$

For the best analysis of the Markov chain, according to Rodríguez (2019), the Transition Matrix is established, within this the following can be considered:

- **Stochastic matrix**:

It is a square matrix whose elements are nonnegative and such that the sum of the elements in each row is equal to 1.

- **One-Step Transition Matrix**:

Given a Markov chain with k possible states E1, . . ., Ek and stationary transition probabilities.

TABLE 1. Technical means used in the harvest transport, according to agricultural yield and distance to be transported

Ra, t/ha		**70**	**65**	**75**	**90**	**22,8**
Harvest aggregate		2 CASE IH 8800 harvesters and 2 BELARUS 1523 tractors + VTX 10000 dump trailer (10 t).				
Transportation aggregate		KAMAZ + 1 trailer	HOWO SINOTRUCK + 2 trailers			
Qn, t		20	60			
Distance, km		20	18	20	24	18
Distance, km	**Asphalt**	7	6	7	9	6
	Embankment	13	12	13	15	12

$$\text{Si } p_{ij}=P\left(X_{n+1}=E_j \middle| X_n=E_i\right)\rightarrow P=\begin{pmatrix} p_{11} & \cdots & p_{1k} \\ p_{12} & \cdots & p_{2k} \\ \vdots & & \vdots \\ p_{k1} & \cdots & p_{kk} \end{pmatrix} \quad (5)$$

The transition matrix P of any finite Markov chain with stationary transition probabilities is a stochastic matrix (Rodríguez, 2019).

According to Rodríguez (2019) Markov model, based on its foundations and applications, can be used in the formation of the sugarcane harvest-transport-reception system, for, based on the probability of passing from one link to another, to determine the stability of the system, that is, it is used as an additional conformation method, which allows, with various possibilities of structures of the complex harvest-transport-reception of sugarcane, to determine which is the most stable. In the particular case of this research, to establish the model, the authors start from the definition of the states that make up the process, which are: sugarcane in harvest Ec, sugarcane in transport Et and sugarcane in the reception center Er, defining sugarcane as the element that transits, since it goes from being in the field to being cut, then it is transported out of the field and towards the mill, where it is unloaded, classified and processed. After specifying the states, the number of necessary means of transport is defined and combined with the transition probability criteria from the elaborated matrix.

In order to form the transition matrix, the probability of transition or non-transition from one state to another must be determined through the Poisson tables as shown in expression (6)

$$Pt_{(x)}=\frac{e^{-\lambda *}\lambda^{n}}{x!} \quad (6)$$

The probability of transition from the state of cane in harvest to that of cane in transport and from this to be unloaded at the reception center will be defined, based on the fact that the necessary inputs are available for their correct exploitation, due to reliability of the technical means involved in the process (Rodríguez, 2019).

For the harvest, it is determined from the coefficient of technical availability of the harvester, because what defines the transition from the cane state in harvest to transport depends on the operation of the harvester:

$$\lambda_c=n_c{*}k_{d_c} \quad (7)$$

where:

n_c - number of combines;

For transport, the technical availability of it is taken into account, since it is what defines that the cane can go from the state of transport to cane in the reception center:

$$\lambda_t=n_t{*}k_{dt} \quad (8)$$

where:

n_t - number of trucks (Rodríguez, 2019).

For users of agricultural technology, complex reliability indices are of great interest, which allow the machine to be evaluated not only from the point of view of the economic feasibility of its purchase, but also to determine the costs related to technical maintenance, repairs and shutdowns due to technical reasons. Of these complex reliability indices, the most widely used is the coefficient of technical availability Kd, which is also used as one of the world-class indices for the control of maintenance management in agriculture, industry and other spheres of production (Shkiliova, 2004).

From the calculation of the mathematical expectation of the functioning of the technical means in the sugarcane harvesting and sugarcane transport states (λc and λt) determined by expressions 5 and 6, the transition probability is established using the Poisson tables where x is the value of the number of technical means in each state.

For the determination of the mathematical expectation of the operation of the technical means in the sugar cane state in reception λcr, 15 observations are made that are averaged determining the number of trucks waiting to deliver the product (ncer) and the total number of trucks in the center receiving (ntr);

$$P_{nt}=\frac{n_{cer}}{n_{tr}} \quad (9)$$

Taking into account the non-transition probabilities in each state, the transition probabilities can be obtained

$$P_{t=}1-P_{nt} \quad (10)$$

Then, the transition matrix shown in expression 11 is built (Rodríguez, 2019). The product of the transition probabilities indicates the probability that the flow harvest will work, which allows determining from the solutions proposed in each model, which will make the system work with fewer stops, that is, more stable.

$$\begin{array}{cc} & \begin{matrix} E_c & E_t & E_r \end{matrix} \\ \begin{matrix} E_c \\ E_t \\ E_r \end{matrix} & \begin{pmatrix} P_{nt} & P_t & 0 \\ 0 & P_{nt} & P_t \\ P_t & 0 & P_{nt} \end{pmatrix} \end{array} \quad (11)$$

Based on the analysis previously carried out, an estimate of the economic impact of the cycle break Cpet can be obtained from the determination of the costs for stops in each element of the cycle and the probability that it does not transit from one state to another of the cycle (Rodríguez, 2019).

$$C_{pet=}\left(C_{pc}{*}P_{ntc}\right)+\left(C_{pt}{*}P_{nt_t}\right)+\left(C_{pcr}{*}P_{nt_r}\right);\text{peso/h} \quad (12)$$

where:

Cpc, pt and cr- cost per stop at the harvest, transportation and reception center of the mill, respectively; weight/hour

Regarding the costs for stops at the reception center, the salary of the workers linked to the process, the fuels and lubricants consumed in the process, as well as the maintenance and the electrical energy consumed are taken into account, as shown in expression 13 (Rodríguez, 2019).

$$C_{pcr}=C_s \pm C_c \pm C_{mr} \pm C_e, \text{ peso/h} \quad (13)$$

DISCUSSION OF THE RESULTS

In order to determine which of the mathematical models used offers the formation of the most stable and economically feasible system in determining the rational composition of the media involved in the process, the Markov model is used, for which three states for its resolution were defined, which were the cane in harvest Ec (harvest subsystem), the cane in transport Et (transport subsystem) and the cane in reception Er (reception subsystem). For the application of this model, through the SACRCCT-CA version 1.0 system, the mathematical expectations (λm) were determined for the state of cane at harvest, in transport and reception (the latter only for the queuing theory model with consecutive or in cascades stations) necessary to obtain the non-transition values using the Poisson tables. Starting from it, their transition probability is determined. The coefficients of technical availability of the harvesters, the means of transport and the reception center are also determined.

Table 2 shows the formed transition matrices and it can be seen that as the number of technical means increases (combine harvesters, dumpers, trucks and reception centers), as the coefficients of technical availability do not vary much, the probability of transition increases, thus decreasing the chance that the process flow will be interrupted. In the state of cane at harvest and cane at reception, the results obtained were analyzed together using linear programming and queuing theory for a single service station, since in the case of the harvest, the values coincide and in the case of the center of reception, the criterion used to analyze the probability of transition and non-transition is the same. As it can be seen in all the matrices, the value of the probability of the passage of the cane from the state in harvest to the state of reception is null, since the cane has to be transported, likewise, the probability of the passage of the cane of being transported to the state in harvest is zero, because once the cane is cut it begins to be transported, a similar situation occurs in the state of cane in reception, because once the cane arrives at the mill it is not returned.

When linear programming (PL) is used in all the variants analyzed, the probability of passing to the reception state is 77%, with a probability of not doing so of 23%, which may be due to a breakage of the harvester or a lack of means of transport. The same happens with the rest of the models in the other variants except for variants II, IV and V, when the formation of the system is analyzed with the cascade queuing theory model, in both cases the transition probability is 80.5%, these being the most stable.

In the case of the transport state, the probability of transition to the reception center is between 75 and 80% for variants I, II and V when the cascaded queuing theory method (TCc) is used, and in variant II in the rest of the models used. In the other models and variants, it is between 80 and 83%.

In the reception state in the linear programming and queuing theory models for a single service station (TCeus), as well as in variant I when the cascade queuing theory is used, the transition probability is between 76 and 78%, being 82% when the cascade queuing theory method is used in variants II to V.

After having defined the transition matrices, the economic impact due to instability or technological failure of the different cycles that represent the different conformations of the sugarcane harvest-transport-reception complex was determined (Figure 1 and Table 3).

In variant I, the lowest loss due to system stops and the highest stability is obtained with the conformation proposed by the cascade queuing theory (two CASE AUSTOFT IH 8800 combines, two BELARUS 1523+ VTX 10000, two HOWO SINOTRUK+ two TRAILERS (each one) and two reception centers) with a minimum cost per stops (CpctrC) of 34.06 peso/h (10.77 and 0.91 pesos/h less than if linear programming and single-station of service queuing theory are used). With this conformation, the probability of transition of the cane from the harvest to the transport is 73%, from the transport to the reception of 80.9% and of being processed in the reception center of 76%, being the probability that the cycle is completed of 42.34%.

In variant II, the method that shows the best results in terms of stability and minimum economic losses is also the cascade queuing theory (two CASE AUSTOFT IH 8800 combines, four BELARUS 1523+ VTX 10000, two HOWO SINOTRUK+ two TRAILER (each one) and three reception centers) with a loss due to system stops of 32.74 peso/h (6.48 and 3.94 pesos/h less than if linear programming and single service station queuing theory were used). With this conformation, the probability of transition of the cane from the harvest to the transport is 80.5%, from the transport to the reception of 73%, of being processed in the reception center of 82% and that the harvest is fulfilled in flow of 48.16%.

Likewise, in variant III, the best results are obtained with the proposed mathematical method, being the optimal configuration of two CASE AUSTOFT IH 8800 combines, two BELARUS 1523+ VTX 10000, four KAMAZ+ one TRAILER (each one) and three reception centers with a loss due to system stops of

TABLE 2. Transition matrices obtained according to the mathematical model used

Model Ra, t/ha	PL	TCeus	TCc
22,8	$\begin{array}{cc} & \begin{array}{ccc} E_c & E_t & E_r \end{array} \\ \begin{array}{c} E_c \\ E_t \\ E_r \end{array} & \begin{pmatrix} 0,27 & 0,73 & 0 \\ 0 & 0,194 & 0,806 \\ 0,77 & 0 & 0,23 \end{pmatrix} \end{array}$	$\begin{array}{cc} & \begin{array}{ccc} E_c & E_t & E_r \end{array} \\ \begin{array}{c} E_c \\ E_t \\ E_r \end{array} & \begin{pmatrix} 0,27 & 0,73 & 0 \\ 0 & 0,17 & 0,83 \\ 0,77 & 0 & 0,23 \end{pmatrix} \end{array}$	$\begin{array}{cc} & \begin{array}{ccc} E_c & E_t & E_r \end{array} \\ \begin{array}{c} E_c \\ E_t \\ E_r \end{array} & \begin{pmatrix} 0,27 & 0,73 & 0 \\ 0 & 0,238 & 0,762 \\ 0,762 & 0 & 0,238 \end{pmatrix} \end{array}$
65	$\begin{array}{cc} & \begin{array}{ccc} E_c & E_t & E_r \end{array} \\ \begin{array}{c} E_c \\ E_t \\ E_r \end{array} & \begin{pmatrix} 0,27 & 0,73 & 0 \\ 0 & 0,27 & 0,73 \\ 0,77 & 0 & 0,23 \end{pmatrix} \end{array}$	$\begin{array}{cc} & \begin{array}{ccc} E_c & E_t & E_r \end{array} \\ \begin{array}{c} E_c \\ E_t \\ E_r \end{array} & \begin{pmatrix} 0,271 & 0,729 & 0 \\ 0 & 0,223 & 0,778 \\ 0,77 & 0 & 0,23 \end{pmatrix} \end{array}$	$\begin{array}{cc} & \begin{array}{ccc} E_c & E_t & E_r \end{array} \\ \begin{array}{c} E_c \\ E_t \\ E_r \end{array} & \begin{pmatrix} 0,195 & 0,805 & 0 \\ 0 & 0,27 & 0,73 \\ 0,82 & 0 & 0,18 \end{pmatrix} \end{array}$
70	$\begin{array}{cc} & \begin{array}{ccc} E_c & E_t & E_r \end{array} \\ \begin{array}{c} E_c \\ E_t \\ E_r \end{array} & \begin{pmatrix} 0,27 & 0,73 & 0 \\ 0 & 0,191 & 0,809 \\ 0,78 & 0 & 0,22 \end{pmatrix} \end{array}$	$\begin{array}{cc} & \begin{array}{ccc} E_c & E_t & E_r \end{array} \\ \begin{array}{c} E_c \\ E_t \\ E_r \end{array} & \begin{pmatrix} 0,27 & 0,73 & 0 \\ 0 & 0,191 & 0,809 \\ 0,78 & 0 & 0,22 \end{pmatrix} \end{array}$	$\begin{array}{cc} & \begin{array}{ccc} E_c & E_t & E_r \end{array} \\ \begin{array}{c} E_c \\ E_t \\ E_r \end{array} & \begin{pmatrix} 0,27 & 0,73 & 0 \\ 0 & 0,191 & 0,809 \\ 0,82 & 0 & 0,18 \end{pmatrix} \end{array}$
75	$\begin{array}{cc} & \begin{array}{ccc} E_c & E_t & E_r \end{array} \\ \begin{array}{c} E_c \\ E_t \\ E_r \end{array} & \begin{pmatrix} 0,27 & 0,73 & 0 \\ 0 & 0,194 & 0,806 \\ 0,77 & 0 & 0,23 \end{pmatrix} \end{array}$	$\begin{array}{cc} & \begin{array}{ccc} E_c & E_t & E_r \end{array} \\ \begin{array}{c} E_c \\ E_t \\ E_r \end{array} & \begin{pmatrix} 0,27 & 0,73 & 0 \\ 0 & 0,194 & 0,806 \\ 0,77 & 0 & 0,23 \end{pmatrix} \end{array}$	$\begin{array}{cc} & \begin{array}{ccc} E_c & E_t & E_r \end{array} \\ \begin{array}{c} E_c \\ E_t \\ E_r \end{array} & \begin{pmatrix} 0,195 & 0,805 & 0 \\ 0 & 0,184 & 0,816 \\ 0,82 & 0 & 0,18 \end{pmatrix} \end{array}$
90	$\begin{array}{cc} & \begin{array}{ccc} E_c & E_t & E_r \end{array} \\ \begin{array}{c} E_c \\ E_t \\ E_r \end{array} & \begin{pmatrix} 0,27 & 0,73 & 0 \\ 0 & 0,194 & 0,806 \\ 0,77 & 0 & 0,23 \end{pmatrix} \end{array}$	$\begin{array}{cc} & \begin{array}{ccc} E_c & E_t & E_r \end{array} \\ \begin{array}{c} E_c \\ E_t \\ E_r \end{array} & \begin{pmatrix} 0,27 & 0,73 & 0 \\ 0 & 0,194 & 0,806 \\ 0,77 & 0 & 0,23 \end{pmatrix} \end{array}$	$\begin{array}{cc} & \begin{array}{ccc} E_c & E_t & E_r \end{array} \\ \begin{array}{c} E_c \\ E_t \\ E_r \end{array} & \begin{pmatrix} 0,195 & 0,805 & 0 \\ 0 & 0,223 & 0,778 \\ 0,82 & 0 & 0,18 \end{pmatrix} \end{array}$

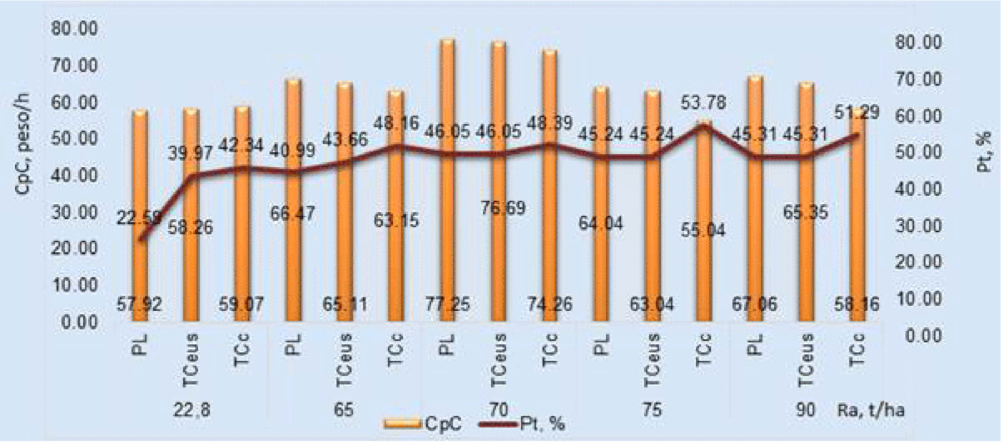

FIGURE 1. Costs for stops and probability of transition of the system.

38.33 peso/h (3.35 and 3.05 peso/h less than if linear programming and single service station queuing theory were used). With this conformation, the probability of transition of the system is 48.39%, being that of the cane from the harvest to the transport of 73%, from the transport to the reception of 80.9% and of being processed in the reception center of 82%.

In variant IV, the same value of losses due to system stops (25.54 peso/h) is obtained when analyzed with linear programming and the single service station queuing theory, reducing losses to 9.53 and 8.98 peso/h when using the conformation variant resulting from applying the queuing theory in cascades, which consists of two CASE AUSTOFT IH 8800 combines, four BELARUS 1523+ VTX 10000, four HOWO SINOTRUK+ two TRAILERS (each one) and three centers of reception. With this conformation, the probability of transition of the cane in the harvest to the transport is 80.5%, from the transport to the reception of 81.6% and of being

TABLE 3. Economic impact of the models used

Ra, t/ha	Mathematical Method	Cp, peso/h	Pt, %	Pnt	Cpctr, peso/h
22,8	PL	57,92	22,59	0,77	44,83
	TCeus	58,26	39,97	0,60	34,97
	TCc	59,07	42,34	0,58	34,06
65	PL	66,47	40,99	0,59	39,22
	TCeus	65,11	43,66	0,56	36,68
	TCc	63,15	48,16	0,52	32,74
70	PL	77,25	46,05	0,54	41,68
	TCeus	76,69	46,05	0,54	41,38
	TCc	74,26	48,39	0,52	38,33
75	PL	64,04	45,24	0,55	35,07
	TCeus	63,04	45,24	0,55	34,52
	TCc	55,04	53,78	0,46	25,44
90	PL	67,06	45,31	0,55	36,67
	TCeus	65,35	45,31	0,55	35,74
	TCc	58,16	51,29	0,49	28,33

processed in the reception center of 82%, existing a 53.78 % probability that the process will occur in flow.

In variant V, the method that shows the minimum losses due to system stops is the theory of queuing in cascades with 28.33 peso/h, so it is recommended that the system be made up of two CASE AUSTOFT IH 8800 combines, four BELARUS 1523+ VTX 10000, three HOWO SINOTRUK+ two TRAILERS (each one) and three reception centers, with the probability of transition of the system being 51.29%, that the cane goes from harvest to transport is 73%, from transport to receiving 77.8% and being processed at the receiving center 82%.

As shown in Figure 1 and Table 3, in all cases, when the cascading queuing theory method is used, the highest probability of transition in the entire system is obtained, that is, it is more likely that the cycle flow is kept, the most stable conformations being those offered by this method for fields of 75 and 90 t/ha (53.78 and 51.29% respectively) and in which the losses due to system stops are lower.

In fields with an estimated agricultural yield of 22.8 t/ha, the probability of transition produced by the solution using any method is low, this being another element that calls into question the convenience of working in agricultural fields with such low yields.

When analyzing the conformation of the harvest-transport-reception system that was used in the real process, with which that showed by each mathematical model (Figure 2), it can be observed that in the fields of 22.8 t/ha it is proposed to reduce the number of external transport aggregates when linear programming and queuing theory methods are used for single service stations. When working in fields of 65 t/ha, the difference is that with the queuing theory method for single stations, it is proposed to increase the number of external means of transport to three, while when using the cascade queuing theory method, it is proposed to increase the number of internal means of transport from two to four. In the fields of 65 t/ha of estimated agricultural yield, it is proposed with all the methods to double the number of external transport aggregates, the same thing happens in the fields of 75 t/ha when the queuing theory method is used and in the 90 t/ha when using linear programming and queuing theory methods for single service stations. In the fields with the last two related agricultural yields, it is proposed to double the number of internal transport aggregates when the cascade queuing theory method is used to form the system.

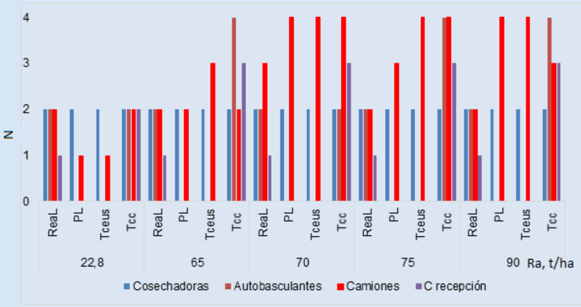

FIGURE 2. Composition of the real system and that obtained by mathematical methods.

Regarding the number of reception centers, as it can be seen in Figure 2, when working in all the fields, using the cascade queuing theory method, it is proposed to increase them (to two when harvesting in fields of 22.8 t /ha and three in the rest), which would reduce transport cycle times and waiting times for external means of transport in the field, helping to reduce costs due to system stops.

Likewise, when analyzing the costs per stops that were obtained experimentally, with those obtained by integrating the mathematical methods of linear programming, queuing theory of single stations and queuing theory in cascades with the Markov chain method (Figure 3), it can be observed that the difference ranges between 17.34 and 44.86 pesos/h, reducing the costs for stops calculated between 27.89

and 68.31% compared to those obtained experimentally.

In order to know in what percentage, the costs for stops decrease, if the conformations of the proposed systems are established, Figure 4 should be observed. In fields of 22.8 t/ha, the costs for stops decrease by 28.12 peso/h, which represents 54.78% of those obtained experimentally, while in the fields of 65 t/ha the decrease would be 46.48% (37.69 peso/h). In the fields of 70, 75 and 90 t/ha it decreases by 42.19; 44.86 and 44.84peso/h, which represents 47.60; 36.19 and 38.72% of the costs for system stops obtained experimentally.

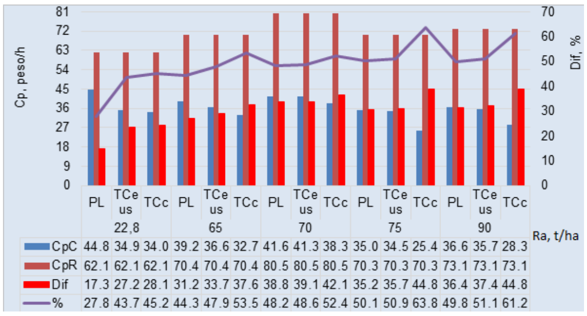

FIGURE 3. Comparison of the costs per stops obtained experimentally with those calculated according to the mathematical model used.

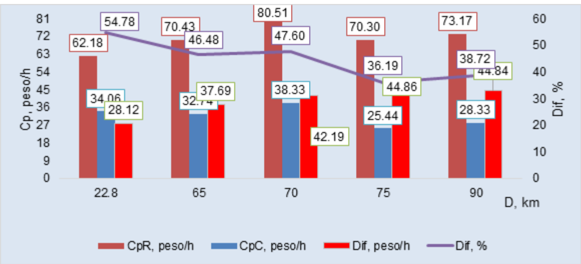

FIGURE 4. Comparison of costs per stop

CONCLUSIONS

- When analyzing the stability of the compositions with the Markov chain model, the most stable variant found was the one resulting from forming the system with the cascade queuing theory method when working in fields of 75 t/ha, with two CASE IH 8800 combines and four BELARUS 1523 Tractors + four VTX 10000 dump trailers, four HOWO SINOTRUCK aggregates + two trailers and three reception centers with a probability of 53.79% that the cycle will not be interrupted and a cost for system stops of 33.05 peso/h.
- From the rationalization criteria, based on the integration of mathematical models, it is possible to reduce the costs per stops by more than 30%, observing a marked influence when increasing the number of collection centers.

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