A Petri nets approach for simulation and control of castor bean biodiesel supply chain

Bruno de Athayde Prata[1] João Bosco Furtado Arruda[2]

Giovanni Cordeiro Barroso[3]

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Abstract- **Nowadays many countries present critical problems related to energy demand-supply equilibrium. Petroleum-based reserves are unable to face future demand for more than few decades. So, the search for alternative sources of energy has been strongly directed to biofuels. Several fruit oils can be used as a source for biodiesel production and the castor bean is an example. The castor bean agribusiness is based in a complex commodity chain, making necessary researches for the improvement of the performance of this chain. This paper put forward a new approach, based on the principles of Supervisory Control Theory and Petri nets, aiming the co-ordination of logistics flows in agribusiness chains and focusing the castor bean biodiesel supply chain. A new method for the supervisory control based on colored Petri nets was developed, called Constraints of Control on Decomposed Colors (CCDC). Also, it is proposed a framework for supervisory control in logistics systems which support agriculture chains. Most of the relevant activities in the castor bean biodiesel supply chain were surveyed to support the proposed modeling process. A mathematical model was developed using Petri nets and the control constraints of the model could be determined through computational simulation. Two scenarios could be conceived and the controlled system presented an acceptable performance. As conclusion, it seems clear that the proposed approach is a feasible and useful tool for the modeling, control and analysis of agribusiness chains.**

Keywords- Decision Support Systems, Supply chain management, Operations Management.

I. INTRODUCTION

In a near future, it is expected that human society will confront an imminent possibility of an energy supply collapse, as a result of the exhaustion of fossil energy sources, nowadays a prominent element in the energy worldwide sources. The strategy of prioritizing fossil fuel can deplete, in few decades, the deposits of these inputs.

Another inconvenient of prioritizing fossil fuel relates to the environmental issue, once that fossil fuels are responsible for a considerable amount of the emission of pollutants which are harmful to the environment, incurring in damages such as the greenhouse effect and, consequently, the global warming. Therefore, the relevance of the search for other energy sources is noticeable as they will make possible to mitigate such problems..In this sense, other energy sources are biomass, which refers to the plant which accomplish the process of photosynthesis, and animal fats. Both absorb solar energy, being capable of storing it, especially under the oil form, making possible the purpose of moving machines with them.

Many oils originated from biomass today constitute inputs of a new fuel called biodiesel. According to Parente (2003), the biodiesel is a clean, biodegradable and renewable fuel which can replace the mineral diesel with several technical, environmental and economic advantages.

Several vegetable oils can be employed for the production of biodiesel, among which can be reported soya, peanuts, cotton, palm, babassu and the castor bean. The latter is a much disseminated culture in Brazil, especially in the north-eastern semi-arid region.

The seeds of castor bean have high energetic value and, when they are crushed, culminate in the formation of oil and mass residuals. The castor bean oil has several industrial applications, such as the production of biodiesel, while the mass residuals can be employed in the production of animal ration with a high rate of lipids and proteins, as well as compost. Conjointly with the obtaining of oil and mass residuals, it can be obtained from the castor bean cellulose (originated from its stalk and root structure) and silk (originated from the feeding of silkworms with its leaves).

The castor bean agribusiness is constituted of a complex supply chain, involving several inputs, products and sub products (ARRUDA and MENDES, 2006). In this way, efforts directed to improve the performance of this chain become necessary in order to maximize its benefit/cost ratio.

The objective of this paper is to report the conception and application of a simulation and supervisory control model, based on colored Petri nets, which allows the coordination of activities in the context of Castor Bean Biodiesel Supply Chain (CBBSC), aiming to guarantee its effectiveness.

The paper is divided in five sections included this one: in the second section, the CBBSC is reported; in the third section, concepts about supervisory control, Petri nets and a new method of synthesis of supervisors denominated Constraints of Control on Decomposed Colors (CCDC) are presented; in the fourth section, a proposal about architecture of supervisory control for logistical systems and the modeling of CBBSC are described – a proposal about control of such system and the evaluation of its performance; finally, in the

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About[1]-Bruno de Athayde Prata: Federal Institute of Education, Science and Technology, Quixadá, Brazil. E-mail: baprata@ifce.edu.br
About[2]-João Bosco Furtado Arruda. Program in Logistics and Operations Research,Federal University of Ceará, Brazil.
E-mail: barruda@glen.ufc.br.
About[3]-Giovanni Cordeiro Barroso. Program in Logistics and Operations Research, Federal University of Ceará, Brazil. E-mail: gcb@fisica.ufc.br

fifth section, conclusions about the study and suggestions for further research are presented.

II. CASTOR BEAN BIODIESEL CHAIN: SOME RELEVANT ASPECTS

The castor bean (Ricinus Communis L.) is an oleaginous of relevant economic and social importance, whit several applications in industry and agribusiness, found in many different regions of Brazil.

Its seeds, after being industrialized, originate mass residuals and the oil which, among other several utilities, are employed in the production of plastic, metals, prosthesis, soaps, perfumes, leather, inks and varnishes, and is also an excellent lubricant oil for motors of high rotation as well as a fuel for using in diesel motors. Its oil presents density higher than other vegetable oils. Its density (at 15°C) varies from 0,945 to 0,965 and it starts boiling at 265°C. Due to these properties, allied with its high degree of viscosity, it is a remarkable lubricant for plane motors and has several industrial applications.

Its mass residuals constitute good organic compost and, when it is denitrified, can be exploited as animal ration. Its stem can be utilized in the paper industry and its leaves, when they are added to the ration, increase cow's milk secretion. Also leaves are useful to feed silkworms culture. It is noticeable that every residual in the exploration of the castor bean plantations can be exploited.

According to Parente (2003), what one has been denominating "biodiesel" is a renewable, biodegradable and environmentally correct fuel, a substitute to the mineral diesel oil, constituted of a mixture of methyl ethers or ethylic long chain acids, obtained from the reaction of transestherification of any triglyceride with an alcohol of short chain (methanol or ethanol).

In Brazil, the process of biodiesel production is already consolidated under the technical and the technological perspective. And there are many resources, not only human ones but also machinery ones to this purpose. On the other hand, the productive system as a whole, from the production of the raw materials to the commercialization of the fuel itself is still too scattered.

The Castor Bean Agro industrial System (CBAS) can be defined as the set of inter-related chains which are inherent to the products and sub products of the castor bean, whose focus extends to the production and acquisition of the inputs to the delivery of the finishes goods to the final clients. The Castor Bean Biodiesel Supply Chain, denoted in this work by CBBSC, may be faced as the main product of the CBAS, being divided in the macro-segments (FREITAS and NOBRE JÚNIOR, 2004):

(i) Production of raw materials: relates to the inputs stocklists, whatever they are seeds, composts, machines and equipment, as well as the agricultural producers;

(ii) Industrialization: includes companies which accomplish industrial activities along the chain, such as crushing and refining;

(iii) Distribution: involves the actors having partnership with the final clients of the productive chain, as, for example, exporters, gas stations and logistical operators.

Arruda et al (2005) propose a governing model for the Castor Bean Biodiesel Supply Chain, aiming to integrate the actors which participate in the chain, in such a way to guarantee its competitiveness in the global market. Such model consists of a structure composed of three actors (ARRUDA and MENDES, 2005):

Local Co-operative Societies (LC): consists of a board, elected by the whole set of producers in a given area, who have the function of organizing the commercial and accountant policies and practices of the group, managing the crushing plants and controlling all the production of the area which is covered by the co-operative;

(ii) Central Co-operative (CC): consists of a board formed by the elected directors of the local co-operative societies, and also by the organization in charge of the managing of the productive chain. It has as a goal to supervise the management of the chain as a whole and to control its performance dictating rules to the chain managing organization (chain logistical operator);

(iii) Manager of the Productive Chain (MPC): consists of an public interest civil society organization, composed of a technical body highly qualified. It must manage the chain activities in a way that it would be free of political impositions, aiming to its effectiveness and always prioritizing actions guided by equity and justice in distributing its benefits among its supporters.

Arruda and Mendes (2006) present a diagnosis on CBBSC in the State of Ceará, Northeastern Brazil. The authors identify causes of the decline of the castor bean production and assert that the chain, which is still budding, only can succeed in its objectives if an effective planning would be made, in order to very coordinate the actions of the actors who are involved in the chain processes.

III. SUPERVISORY CONTROL OF DISCRETE EVENTS SYSTEMS

According to Athey (1982), from the decade of the sixties on, researchers developed ideas which turned out to found an area of knowledge known as System Analysis. The Systems Analysis is adopted for characterization and searching solutions of complex problems, involving iterative processes, as well as interactions with the system environment and the kind of inner control of these processes. Concerning the System Analysis there are different modeling paradigms, among which can be reported the Discrete Event Systems. According to Cassandras and Lafortune (1999, p. 36), "A Discrete Event System (DES) is a system of discrete states and directed to events, that is, the evolutions of its states in its totality depends on the occurrence of the discrete events asynchronous along the time."

Applications of DES are various as, for example, manufacturing, robotics, traffic control, telecommunication, transportation, logistics and computer science. These applications require control and coordination of activities aiming to discipline flux of events.

Any system has, in general, a wide variety of events with a probability of occurrence. Therefore, a model of a system of this nature would represent its uncontrolled behavior, that is, so many desirable events as many undesirable events can occur.

Starting from the premise that this kind of behavior is not satisfactory, it can be modified by control. The modification of the system behavior can be accomplished by the restriction of its functioning to a subset of events possible of occurring in the uncontrolled system.

The Supervisory Control Theory (SCT) was idealized by Ramadge and Wonham at the end of the eighties and it was based on the utilization of mathematic formalisms to limit the occurrence of events in models of DES (RAMADGE and WONHAM, 1989).

The problem of the supervisory control consists of synthesizing a supervisor that coordinates the subsystem activities in a way that the general system satisfies a set of specifications (IORDACHE and ANTSAKLIS, 2006).

According to Sigrimis et al. (2001), the agricultural sector has becoming an industry of great importance and must count on massively on advanced systems of management and control, integrated by computers. Efforts in this direction culminated in the formation of the technological area named as “Agroinformatics” (KOUMBOULIS et al., 2006).

Wolfert et al. (1997) propose a computerized system to control processes in the food production sector. The premise for the application of such architectural control is the development of a model which represents the involved processes to be monitored. The model interacts with two different domains: the domain of business control, which refers to the panning and the control of the company as a whole, including managerial functions such as investments management, allocation of resources, marketing, sales, among others, and the domain of control of processes, which refers to production, involving not only the activities of agricultural production but also the logistical functions of stocking and transportation. Based on Information Technology (IT), data about the managerial physical processes are processed, resulting in interfaces for the supervisory control, the quality control and the processes optimization.

Folinas et al. (2003) present a computerized system, based on the internet, for the integration of data and processes in supply chains in the agribusiness sector. Such a system unifies the agricultural producers, processing industry, retailers, wholesalers, producers’ cooperatives and distributors in a system via web, sharing information in real time and coordinating logistical activities along the supply chain, aiming to minimize the service time of requests and costs involved.

According to Koumboulis et al. (2006), the noticeable advancements in the area of agroinformatics concerns the development of Decision Support Systems (DSS), which aims to monitor all the functions of an agribusiness process, supporting the decision making by proposing scenarios and performance evaluation of the system. Such authors propose an architecture for a DSS in the agribusiness sector, based on SCADA (Supervisory Control and Data Acquisition) systems. Information about the agricultural activities supplies three agents: an operator agent, which consists of a system that has artificial intelligence, a monitoring agent of the weather and a logistic agent.

The intuitive graphic representations, as well as its powerful algebraic formulation, show the Petri nets as one of the best methods to the supervisory control of DES (MOODY and ANTSAKLIS, 1998; IORDACHE and ANTSAKLIS, 2006).

According to Murata (1989), Petri nets are a kind of bipartite, directed and weighted graph, which can collect the dynamic of a DES. Petri nets provide a compact representation of a system once they do not represent explicitly all the space of states of the modeled system.

A place can be utilized as an indication of a state of the system (set of the current values of the parameters which define a certain system, in a given instant) to the DES modeled. The tokens indicate that the conditions associated to the places are true. Transitions can represent operations or action accomplished by the system, having the following attributes: identification and time. The attribute “time” exist for the Petri nets with restrictions of time, which indicates the time associated to the firing of transitions (BERTHOMIEU and DIAZ, 1991). An arc which goes from a place to a transition indicates, together with the tokens, the conditions for an action being accomplished.

According to Moody et al. (1994), the invariant places, which are one of the structural properties of the Petri nets which depend only on the topology of the net and are independent of its marking, correspond to the set of places in which the sum of tokens remains constant for all the reachable markings through the net. Control places, that is, places that will submit a net to a pre-determined behavior, can be implemented by the imposition of invariant places to the model.

It is notorious the knowledge about the utility of the Petri nets as a method of support to the decision making in the management of industrial activities. However, considering the limitations of the ordinary Petri nets and the complexity of the systems to be managed, the utilization of the high level Petri nets, and, especially, the utilization of colored Petri nets, facilitates the conception of more compact and robust models, making the analysis of such systems easier. (JENSEN, 1992; DESROCHERS and AL-JAAR, 1995).

The supervisory control is a practical application of the colored Petri nets that can bring remarkable benefits to the management of industrial and logistical activities. The colored Petri nets, due to the complexity of the functions of their arcs and to the exponential growth of the states in the reachability graph, restrict the synthesis of supervisors and make them more difficult.

The idea of analyzing the incidence matrix of the colored Petri nets is not interesting due to the abovementioned reasons. But here we have a question: if the model was treated in a way that the complexity of the incidence matrix is reduced, can such difficulty be overcome?

In the case of functions being expressed in terms of only one variable, it is possible to separate the colors of the net in a way that each function of the arcs can be expressed as an integer number, conforming to the ordinary Petri nets. In this way, the incidence matrix related to each color can be analyzed separately. This is the essence of the method proposed, denominated Constrains of Control on Decomposed Colors (CCDC). The algorithm of the method CCDC is exposed in Figure 1.

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Algorithm CCDC
Start
Step 1
Given a certain DES, one must develop a model in colored Petri nets in a way that the arcs are function of only one variable.
Step 2:
Define the control specifications in a way that its specification does not contain more than one color.
Step 3: Synthesize supervisors utilizing the method of the invariant places, analyzing each color isolated.
Step 4: For each control place inherent to the specification for a color, add the number of tokens correspondent to the initial marking of the other colors.
End
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Figure 1. Algorithm of the method of Constraints of Control on Decomposed Colors (CCDC

IV. SUPERVISORY CONTROL OF DISCRETE EVENTS SYSTEMS

Literature treats of the supervisory control as a method for the coordination of activities in flexible manufacturing systems, energy transmission, transportation and telecommunication.

In this way, a contribution of the present work consists of the definition of a framework for the supervisory control of logistical systems. Based on the work of Zhou (1991), involving control architecture for manufacturing intelligent systems, an adaptation for the case of logistical systems is proposed, as is illustrated in Figure 2. The hierarchy of the conceptual model is composed of three levels, defined as follows:

(i) Decision Maker: the decision maker is the stakeholder that, based on his own knowledge, experience and information, specifies the desired behavior for the logistic system;

(ii) Supervisory controller: the supervisory controller consists of a model of the focused logistic system, based on Petri nets, which produces the evaluation of the system performance under the impositions (specifications) proposed by the decision maker;

(iii) Local controller: a computational system that controls local processes, in operational level, not having a general view of the logistic system as a whole.

The stakeholders, denominated actuators, must actuate on the logistic system, aiming for the implementation of the control specifications, and the sensors must collect the answers produced by the system.

There are two paradigms related to the DES supervisory control: one of them is based on the utilization of information systems that are connected to the processes in real time and the other one in which this condition does not occur.

In the case of the utilization of information systems accompanying the logistic system in real time, the decision maker can be a computer which, based on the collected data and on a knowledge system (such as artificial neural networks or another technique of artificial intelligence for the accumulation of knowledge), determines the actions to be taken by the logistic system. The model is connected in real time to the logistic system and accompanies its activities. Local controllers are computerized systems which execute the specifications delegated by the decision maker. It is pertinent to emphasize that the human participation in the process of decision making is limited under this paradigm and it can even not exist.

On the second paradigm, there is no real time consideration in activities of the logistical system, and the human participation in the system analysis determines which the actions to be executed are. The model makes possible a global view of the system by the analyst, as well as his forecast of how the system is going to behave in given scenarios. The local controllers can be workers that will allow the possibility to make operational (via computers system) the concept and the functional specifications established by the decision maker.

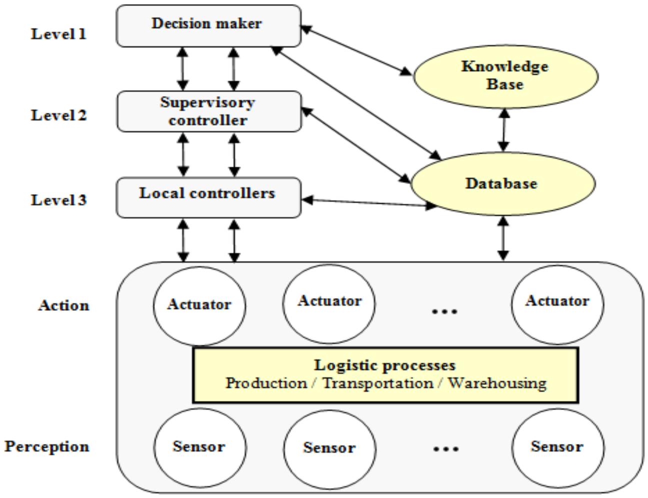

Figure 2 – Proposal of a framework of supervisory control for logistics systems. Source: Adapted from Zhou (1991).

A mapping of the most significant activities of the castor bean biodiesel supply chain was accomplished as a first stage of the modeling process. Such survey was accomplished through bibliographic searches and technical visits to the Secretary of Agriculture Development (SAD/Ceará) and to the Bioenergy Technologies Research Company – TECBIO. Based on that survey, eight main stages of the CBBSC were proposed and described as follows (see, in Figure 3, a scheme of the products and activities along the CBBSC).

The raw material utilized for the production of castor bean are seeds, fertilizers, herbicides and water. The production process is composed of manual activities (fertilizing, liming, plantation and replacement, paring) and mechanized activities (plough). The time of production stage in the tillage, in the Castor Beans Plants (CBP), from the soil preparation to the final growth of the cultures is about three months.

After the harvest, castor bean seeds must be transported to a local of drying and refinement, stages that last, jointly, about four days. After that, the processed harvest must be stocked and then transported from the CBP to the Crushing Plant (CP). This transportation will be feeder, if the CP is located inside the agro industry, or trunk, otherwise.

In the CP harvest will be crushed, thus being divided in oil, net mass residuals and losses. The oil obtained after the crushing of the castor bean is transported to the biodiesel Production Plant (PP), while the net mass residuals is directed to the compost and ration production plants.

The proposed model is restricted to represent the logistical flow inherent to the focused harvest, to the consequent vegetal oil and biodiesel, not considering variants of agricultural, commercial or accounting type. Concerning the supervisory control in agro industrial systems, the present model would contemplate the logistical agent presented in Koumboulis et al. (2006).

Estimated data concerning castor bean production for several cities in the State of Ceará were collected. These data concern the distances on the roads for determination the transport time and also about the equipment's capacity utilized in the focused CBBSC.

Considering the study area and based on castor bean production data, it was possible to realize that the number of producers is quite elevated and, therefore, the geographic dispersion, the capacities of production and its logistical processes are expected to present a great variability. So, the option of modeling the chain using seeds Distribution Centers (DCs) disposed in some places at the study area was adopted.

Then the seeds follow, via highways, to the Crushing Plant (CP), which will transform them into oil. Finally, the oil is transported in trucks to the Production Plant (PP), where the castor bean oil is used as input to biodiesel production. The model do not consider the other sub products of the CBBSC.

Figure 4 presents the CBBSC operational model based on colored Petri nets. In tables 1 and 2 the characteristics of the model are described.

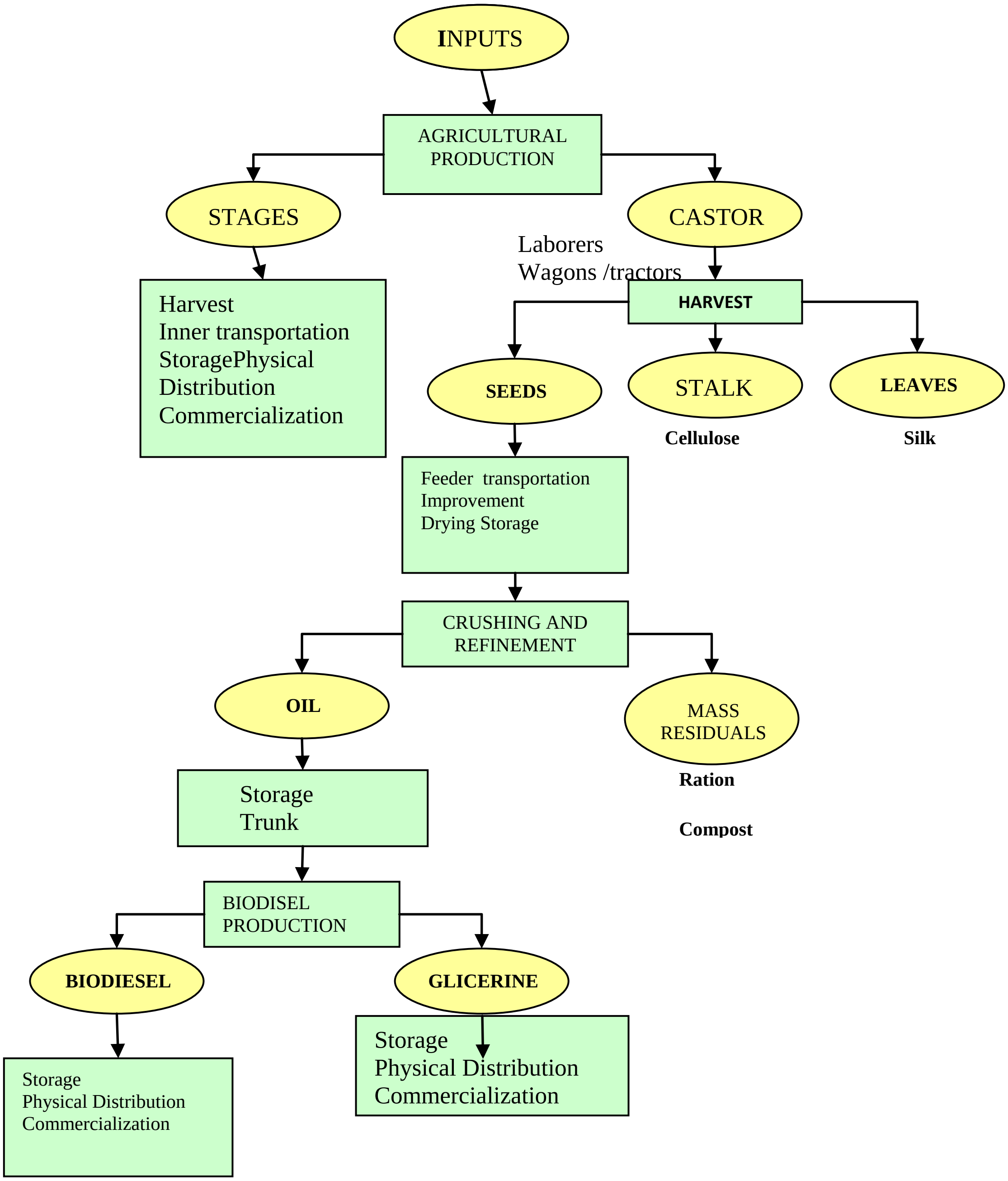

Figure 3 – A simplified diagram of the products and activities in the focused supply chain.

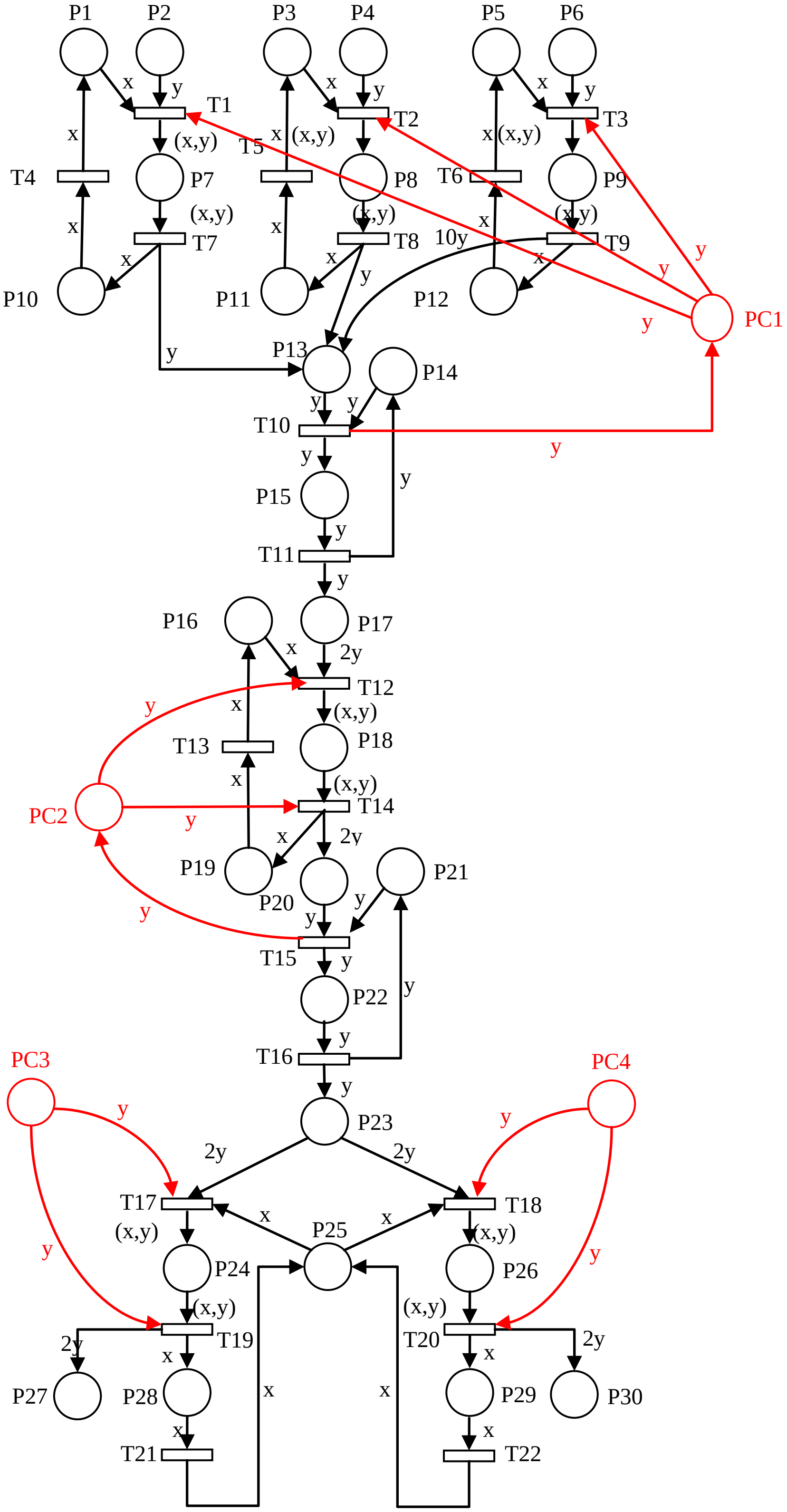

Figure 4. Controlled model of castor

Place	Description	Associated set of colors
P1	Truck available at DC1	C1
P2	Stocked harvest at DC1	C1
P3	Truck available at DC2	C1
P4	Stocked harvest at DC2	C1
P5	Truck available at DC3	C1
P6	Stocked harvest at DC3	C1
P7	Harvest in transit, from DC1 to SP	C2
P8	Harvest in transit, from DC2 to SP	C2
P9	Harvest in transit, from DC3 to SP	C2
P10	Truck ready to return to DC1	C1
P11	Truck ready to return DC2	C1
P12	Truck ready to return DC3	C1
P13	Harvest at SP	C1
P14	Capacity available of the SP	C1
P15	Oil in production	C1
P16	Truck available at SP	C1
P17	Stocked oil	C1
P18	Oil in transit from SP to PP	C2
P19	Truck ready to return to SP	C1
P20	Oil at PP	C1
P21	Capacity available of the PP	C1
P22	Biodiesel in production	C1
P23	Stocked Biodiesel	C1
P24	Biodiesel in transit to the refinery	C2
P25	Truck available at PP	C1
P26	Biodiesel in transit to the port	C2
P27	Biodiesel at the refinery	C1
P28	Truck at the refinery, ready to return to PP	C1
P29	Truck at the port, ready to return to PP	C1
P30	Biodiesel at the port	C1

Table 1. Caption of the places of the net presented in Figure 4.

Transition	**Description**	**Firing Time (min)**
T1	Loading of the truck, with berries, at DC1	60
T2	Loading of the truck, with berries, at DC2	60
T3	Loading of the truck, with berries, at DC3	60
T4	Return of the truck to DC1	99
T5	Return of the truck to DC2	231
T6	Return of the truck to DC3	10
T7	Transport and unloading of the truck, coming from DC1	207
T8	Transport and unloading of the truck, coming from DC2	407
T9	Transport and unloading of the truck, coming from DC3	75
T10	Oil production	48
T11	Oil warehousing	5
T12	Truck loading, with oil	5
T13	Return of the truck to SP	231
T14	Transport and unloading of the truck to PP	352
T15	Biodiesel Production	24
T16	Biodiesel Storage	5
T17	Loading of the truck, with biodiesel	5
T18	Loading of the truck, with biodiesel	5
T19	Transport and unloading of the truck to the refinery	517
T20	Transport and unloading of the truck to the port	573
T21	Return of the truck , coming from the refinery, to PP	345
T22	Return of the truck, coming from the port, to PP	382

Table 2. Caption of the transitions of the net presented in Figure 4

The utilized premises in the modeling are: (i) 1 DC in Canindé (DC1), serving Santa Quitéria and Canindé districts and storage of a harvest of 660 tons; (ii) 1 DC in Quixadá (DC2), serving Quixadá and Quixeramobim districts and stocking a harvest of 180 tons; (iii) 1 DC in Tauá (DC3), serving Tauá and Pedra Branca districts and stocking a harvest of 480 tons, (iv) 1 CP in Quixadá, with capacity of 20 ton/day; (v) 1 PP in Tauá, with capacity of 20m³/day; (vi) 1 biodiesel mill in Fortaleza; 1 port in Pecém; (viii) trucks for the seeds transport, with capacity of 10 tons; and (ix) trucks for oil and biodiesel transport, with capacity of 10.000 liters.

The integer type variable "x" (Figure 4) represents trucks utilized in the distribution of the harvest, oil and biodiesel. If, for instance, we add at place P1 six tokens with x=1, we are going to have six trucks that will be distinguished along the simulations, which is a fact that would not occur if the place-transition Petri nets were utilized.

The integer type variable "y" (Figure 4), represents the harvest that, later on, becomes oil and biodiesel. In an analogous way to that one described in the previous paragraph, the fractions of harvest, oil and biodiesel also may be distinguished along the simulations.

In Figure 4, the set of colors C1 is associated with those places that do not contain tokens of distinct variables at the same time. But the set of colors C2 is associated to the places that may contain tokens with the variables "x" and "y" simultaneously.

The marking of the place p1, correspondent to DC1, will be M(p1) = 66'y, in which each token of the group "y" represents ten tons of harvest. Analogously, the markings of the places p2 and p3 will be M(p2) = 18'y and M(p3) = 48'y.

Evaluating the behavior of this uncontrolled model by simulations, it was possible to identify some problems in the chain processes, according to what is shown as follows.

Firstly, once the harvest production is much superior than the capacity of the PE, a waiting to the appropriate processing of the seeds occurs. The trucks can transport fractions of the agricultural production even if the crushing plant is still not capable to process them. This implies in inefficiency, once an unnecessary intermediary stock is formed. The ideal scenario is that where the fractions of the harvest are transported only in the moment in which they are required by the crushing plant. An analogous problem occurs between the crushing plant and the biodiesel production mills.

Another problem is the biodiesel allocation to the internal and external markets. There must be some other instrument of control which designs the allocation of the fleet to its correct destiny, in a way to avoid failure in the delivery.

From the analysis of the model, it was possible to establish functional specifications for the functioning of the CBBSC and to put into effect the CCDC method. Control places of the net are presented in Table 3 and in Figure 4.

Place	**Description**	**Associated color set**
CP1	Controls the harvest flow between CD and PE.	C1
CP2	Controls the oil flow between PE and PP	C1
CP3	Allocates biodiesel to internal market	C1
CP4	Allocates biodiesel to foreign market	C1

Table 3. Control places of the model

Aiming to the feature of the model as a supporting tool to the decision making in the CBBSC, the option of performance evaluation of the controlled model was adopted.

Concerning the performance evaluation of logistical systems and especially in agro industrial supply chains, Alves (1997, p. 171) highlights that the cycle time is an important measure of logistical performance, which "represents the perception of the client about the period that exists between the request and the reception in the delivery of the product."

In the case of the focused chain, the cycle time will consist of the operational time elapsed considering the transport of the harvest to the Crushing Plant and the arrival of the oil in the biodiesel mill and/or in the port. Such approach is in consonance with the works of Costa (2202), Prata et al. (2006) e Machado et al. (2006).

In the performance evaluation of the system, two scenarios were proposed: (i) Scenario A: 75% of the production directed to the internal market and 25% directed to the foreign market; and (ii) Scenario B: 100% of the production directed to the external market.

Besides both scenarios (A and B) eight operational scenarios were established, aiming to analyze the performance of the system under several circumstances. The values of the markings in the places p_1, p_3, p_5, p_{16} e $p_{25,}$ which correspond to the transport equipment (trucks) employed in the chain, will be the parameters to be varied.

In this context, eight operation systems for propositions A and B were established, aiming to evaluate the behavior of the chain. A summary of the results obtained are presented in Table 4, Table,5 and Figure 5.

Analyzing scenarios A1 and A7, it is noticeable that, allocating only one truck for the transport of oil and biodiesel, the cycle time is much superior compared to the other scenarios. On the other hand, the scenarios in which many trucks are used (A3, A4 and A8), the cycle times tend to decrease.

Scenario	Description of the Scenario	Cycle time (h)
A1	$M(p_4) = 1$, $M(p_5) = 1$, $M(p_6) = 1$, $M(p_{16}) =1$ e $M(p_{25}) = 1$.	1010,6
A2	$M(p_4) = 2$, $M(p_5) = 2$, $M(p_6) = 2$, $M(p_{16}) =2$ e $M(p_{25}) = 2$.	546,8
A3	$M(p_4) = 3$, $M(p_5) = 3$, $M(p_6) = 3$, $M(p_{16}) =3$ e $M(p_{25}) = 3$.	519,4
A4	$M(p_4) = 4$, $M(p_5) = 4$, $M(p_6) = 4$, $M(p_{16}) =4$ e $M(p_{25}) = 4$.	522,7
A5	$M(p_4) = 1$, $M(p_5) = 1$, $M(p_6) = 1$, $M(p_{16}) =1$ e $M(p_{25}) = 2$.	680,0
A6	$M(p_4) = 1$, $M(p_5) = 1$, $M(p_6) = 1$, $M(p_{16}) =2$ e $M(p_{25}) = 2$.	622,9
A7	$M(p_4) = 3$, $M(p_5) = 3$, $M(p_6) = 3$, $M(p_{16}) =1$ e $M(p_{25}) = 1$.	1007,5
A8	$M(p_4) = 1$, $M(p_5) = 1$, $M(p_6) = 1$, $M(p_{16}) =3$ e $M(p_{25}) = 3$.	586,8

Table 4. Summary of the results obtained for scenario A.

Scenario	Description of the Scenario	Cycle time (h)
B1	$M(p_4) = 1$, $M(p_5) = 1$, $M(p_6) = 1$, $M(p_{16}) =1$ e $M(p_{25}) = 1$.	976,2
B2	$M(p_4) = 2$, $M(p_5) = 2$, $M(p_6) = 2$, $M(p_{16}) =2$ e $M(p_{25}) = 2$.	503,3
B3	$M(p_4) = 3$, $M(p_5) = 3$, $M(p_6) = 3$, $M(p_{16}) =3$ e $M(p_{25}) = 3$.	430,2
B4	$M(p_4) = 4$, $M(p_5) = 4$, $M(p_6) = 4$, $M(p_{16}) =4$ e $M(p_{25}) = 4$.	431,7
B5	$M(p_4) = 1$, $M(p_5) = 1$, $M(p_6) = 1$, $M(p_{16}) =1$ e $M(p_{25}) = 2$.	671,1
B6	$M(p_4) = 1$, $M(p_5) = 1$, $M(p_6) = 1$, $M(p_{16}) =2$ e $M(p_{25}) = 2$.	592,3
B7	$M(p_4) = 3$, $M(p_5) = 3$, $M(p_6) = 3$, $M(p_{16}) =1$ e $M(p_{25}) = 1$.	974,3
B8	$M(p_4) = 1$, $M(p_5) = 1$, $M(p_6) = 1$, $M(p_{16}) =3$ e $M(p_{25}) = 3$.	594,8

Table 5. Summary of the results obtained for scenario B.

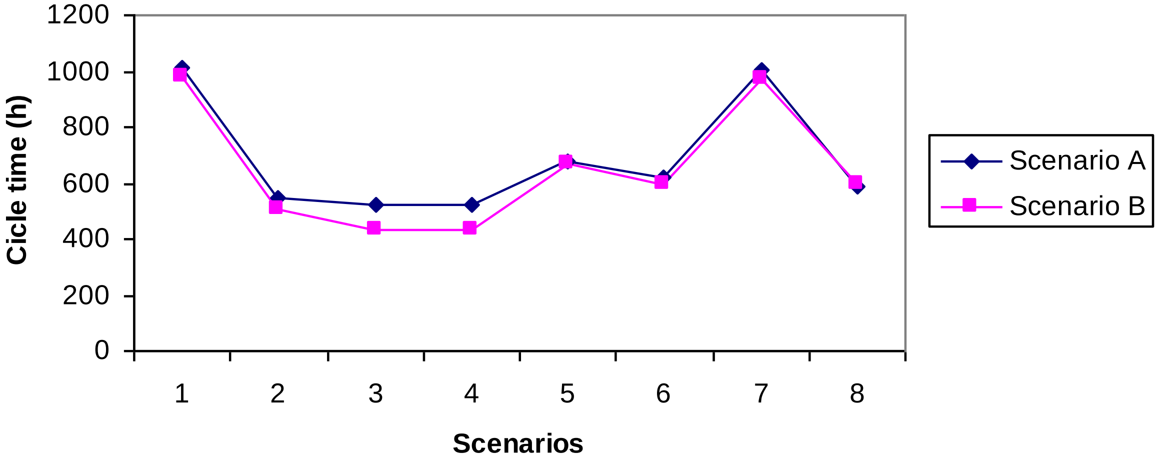

Fig.5. Behavior of the cycle time along the simulated scenarios in alternatives A and B.

Still comparing scenarios A1 and A7, it is noticeable that, when triplicating the number of trucks to the transport of seeds and maintaining the number of trucks to the transport of oil, the reduction in the cycle time is significant. Thus, it is seen that the number of trucks for the transport of seeds have a stronger impact on the cycle than the number of trucks transporting castor bean oil. It is also noticeable that the marginal productiveness, due to the addition of equipments, tends to zero, as it is showed it scenarios A2, A3 and A4. The performance of the system for alternative B was similar to that of the alternative A, considering the variation of the cycle time due to the change in the parameters. However, one can observe that the cycle time for the chain is smaller when the product is directed to serve exclusively the external market.

Distinction between values of cycle times of alternatives A and B is justified by the bigger distance to be covered by the trucks in alternative A, while in alternative B the only destiny is the port. The biodiesel mill, when situated closer to the agricultural supply plants, incurs in smaller transport times. In scenarios 3 and 4, where the value of truck trips is bigger, the discrepancy between the performance of alternatives A and B is bigger.

The system in question has many uncertainties. So, it was decided to build a stochastic model of the focused chain. As field data to the adjustment of probability density functions to the model's transitions were not provided, hypothesis that operational times of the chain are governed by exponential distribution was adopted.

This hypothesis was based on the following considerations:

(i) Exponential distribution has a continuous probability density function and it is normally used in services and operations representations of processes in simulation studies;
(ii) It is a function of just one parameter, which is considered as the firing times of the transitions; and
(iii) According to Bause and Kritzinger (2002), the reachability graph of a colored Petri net is isomorphic to a Markov Chain. Consequently, it is possible to accept that transitions among states are governed by an exponential distribution, in view of its character without memory.

As the model is probabilistic, every time a simulation is made, it will tend to offer distinct results, in terms of cycle time. In this way, after computational experiments, it was decided to turn on the model 100 times in order to obtain a value of mean cycle time that is a good estimator of the system operation time.

V. CONCLUSION

This work presented a proposal for the coordination of logistical activities in agribusiness supply chains based on Discrete Events System (DES) modeling concepts. For this purpose, the Theory of Supervisory Control was utilized, conjointly with the colored Petri nets.

The relevance and originality of the proposed model must be highlighted. Under the practical point of view, the control of the physical flows in supply chains has great importance to a higher efficiency of a logistical system. Under the theoretical point of view, no study which presented a similar proposal was found in the literature. Also, one must highlight the effectiveness of the proposed supervisory control framework for logistical systems: the new method of supervisory control denominated Constraints of Control on Decomposed Colors (CCDC).

The proposed modeling, implemented in the software CPNTools, constitutes a Decision Support System which permits the building of scenarios aiming to the management of the CBBSC. Concerning the application of the supervisory control framework in a real system, hierarchical levels of the system must be planed, as well as the databases, sensors and actuators.

In case of treating rudimentary chains, involving small producers geographically dispersed, as is the case of the central region of the State of Ceará, in the northeastern Brazil, a fully computerized system could incur in a technical and economic unfeasibility. In such a case, it is up to the Manager of the Supply Chain (MSC) to implement a hybrid system (man-machine) to support the decision making in the CBBSC.

Finally, the proposal of the present work fits in the research field of the agroinformatics which promises many deployments (SIGRIMIS et al. 2001; KOUMBOULIS, et al. 2006). As a suggestion for future studies it is proposed that the presented modeling be applied in a real chain, focused on the evaluation of its logistical performance and testing the degree of articulation of sensors and actuators in agro industrial supply chains, especially at the CBBSC.

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