An analysis of the Brazilian ethanol supply chain

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Abstract
The research analyzes the Brazilian ethanol supply chain, using the Theory of Constraints. The results show that supply chains are made up of the production of sugar cane, manufacture, distribution and sale of ethanol. The restrictive stage of the whole supply chain is related to grinding the sugar cane.

Keywords: Ethanol supply chain, Theory of Constraints, Brazil.

Introduction
The ethanol production chain is complex and consists of members that do not work in an integrated manner (Machado and Borges 2008). In this context, the efficient coordination of this important supply chain for the Brazilian energy matrix becomes essential. It is crucial to identify the structure of this production chain, mapping processes and inter-relationships between suppliers and customers that integrate organizations from the production sources of raw materials to the point of consumption of the finished product (Pires 2009). As a means to achieve this goal, this paper proposes the use of the foundations of the Theory of Constraints to identify bottlenecks in the production process of the ethanol system.

Several problems are present in the ethanol production chain, impacting directly on its performance. To express synthetically the existing problems in this production chain emerges the following general research question, addressed as investigative axis for this work: what is the structure of an ethanol production chain (in the state of Goiás in Brazil) and which elements in its constitution configure bottlenecks (from Theory of Constraints point of view)?

In order to develop the research, the following specific questions were identified:

How are relationships between the parts of the ethanol supply chain in Goiás?

What are the existing constraints, along the ethanol production chain in Goiás, from the production of sugar cane to the departure of ethanol to the fuel distributor?

Literature review

Supply Chain Management – SCM

Gusmão (2004) believes that the main problem associated with the supply chains is the management of their main functions required to transform the raw material into the final product
being delivered to the marketplace at the lowest cost and meeting the expectations of customers. It is necessary, therefore, to enhance the integrated management of functions such as purchasing, storage, production, transportation and distribution, framing the concept associated with the Supply Chain Management - SCM.

According to Pires (2009), SCM is clearly multifunctional and covers the interests of various traditional areas of Brazilian organizations. From this perspective it is possible to consider SCM as a contemporary area that certainly has more than one source. Pires (2009) comments about the SCM concept, arguing that it is an integrated way to plan, manage and optimize the flow of goods or products, information and resources from suppliers to the final customers, considering the different processes and activities that produce value to the customers.

To Moellmann (2008), the SCM can be defined as two or more independent companies working together to align their supply processes, aiming at generating benefits not only for the final consumers, but for every company connected, considering that a higher return is expected when working together, which would not happen if they worked individually.

It is concluded that the SCM involves an economic structure, comprising interconnected companies from the manufacture of raw materials to the delivery of finished products to the customers, not only related with the processing, transportation and marketing companies, but with all those companies necessary for the business involved in the supply chain.

Ethanol Supply Chains

According to Almeida et al. (2007) the sugar cane agribusiness consists of generating links to various business opportunities such as production of sugar cane, sugar, ethanol, and several by-products related, among others. Ethanol production is shown as one of the most attractive opportunities within this business. The search for renewable sources of energy, aiming at restructuring the world energy matrix, is making ethanol production grow significantly.

A good representation of the supply chain must include its various links, that can involve agricultural and industrial processes, and suppliers and clients that connect companies from the initial source of raw materials to the point of consumption of the finished product (Pires 2009). In this case, the activities from the lease of land to harvest and transport the raw material should be understood as agricultural processes. Industrial processes, in turn, should be considered as the agents of the transformation of sugar cane to ethanol and its subsequent distribution to points of final consumption.

The ethanol distributing process in Brazil underwent several transformations after deregulation, which occurred in the early 1990s. Until this period, the Brazilian government regulated the pricing policy for the sector and there were only seven major distributor companies in the country, with which the companies producing ethanol could commercialize their products. By 2010 this number had risen to one hundred and forty six distributors spread across Brazil (Ibp 2013).

There are two models of the ethanol supply chains: those working with their own properties or leased properties and those working with external sugar cane suppliers. The former model is featured by the presence of ethanol plants that produce their own raw material, dealing with planting, harvesting and transporting their sugar cane. According to Brito (2012), lands used in this model of supply chain are generally rented (through commercial leasing contracts), for periods of five years and may commonly be extended for another two years, due to the specificity of the sugar-cane cycle. A mill adopts this configuration in the production chain,
because, despite the cost of coordination inherent in this decision, there is the benefit of decreasing uncertainty on obtaining the raw material of inferior quality and thus ensuring the best results in the production of the ethanol. According to Costa et al. (2008), the settings found in this model of supply chain have technical activities such as leasing or acquisition of the land, preparation of the land, planting of the sugar cane, cultivation, harvesting, transportation of feedstock for the ethanol plant, receiving, washing, crushing, treatment of sugar cane juice, distillation, storage of alcohol in the mill, transportation to distributor, storage / certification, transportation to the gas station, and storage and sale of ethanol in gas station.

In supply chains working with external sources, the supplier is responsible for planting, harvesting and transporting of the sugar cane. Management of this model of supply chain deals with an increasing complexity related to the large number of suppliers, but the sequence of activities and transactions after ethanol plant remains the same.

In this research only the internal ethanol production chain involving processes such as planting, harvesting, transportation and preparation of sugar cane, obtaining substrate for fermentation, fermentation and distillation, as proposed by Cortez (2010) was considered as investigation boundaries.

**Analysis of supply chains based on the principles of the Theory of Constraints**

The Theory of Constraints - TOC - is a tool with applications in various areas of expertise and can assist in the evaluation and solution of various types of bottlenecks in simple and complex systems. The TOC approach advocates that the basic objective of companies is to make money. It also considers that manufacturing should contribute to this goal through the basic operations on three elements: material flow passing through the factory, inventory and operating expenses (Cox and Schleier 2010).

To Goldratt et al. (2000), organizations are increasingly competing on the level of supply chains, and to be competitive, they need to look outside the boundaries of the firm, based on the premise that in order to have good performance in all, good performance is required in each link of the entire supply chain.

Hamada (2007) states that the basic goal of the supply chain must be to understand the customer’s needs and quickly provide what they want. Therefore, companies have to manage their relationships with suppliers and customers as best as possible, identifying which link in the chain is the weakest and is influencing the service delivered to the final customer.

Several concepts of TOC are concerned in the SCM. The production planning and control, for example, is based on the synchronization of production processes and requisition of required materials to the supply chain. The performance measurement is another aspect considered, since the TOC suggests that the supply chain exists as a single unit and to be like this, it is important that customers and suppliers follow the schedule suggested. The inventory management is also included in this discussion, suggesting maintaining low inventory levels in all channels of distribution of the supply chain (Sikilero et al. 2008).

Santos et al. (2010) argue that with the implementation of SCM tools, instantaneously the plants can get information from their suppliers on inventory levels. Besides, with the adoption of integrated information systems and continuous improvement programs, they quality and productivity can be improved with the reduction of supply lead-time. However, there is a problem related to the maintaining of inventories levels based on the prediction of consumption in the plants, even when the supply lead times are reduced.
Research method

The research presented in this paper corresponds to a stage of an effort initiated with Machado and Borges (2008) whose seminal goal was to understand the structure of the sugar cane supply chain in the state of Goiás, in Brazil. Also this research aimed to identify the factors that interfered in the efficiency and the connections existing between companies in supply chains of the ethanol industry. The conclusions of that study did not allow for precisely identifying which existing connection in the ethanol supply chain represented a bottleneck for increasing the efficiency of its production flow. This generated the need for more detailed research on that supply chain.

This research has emerged as a complementary study to the work of Machado and Borges (2008), with the proposal of a qualitative and quantitative assessment of some ethanol supply chains, which were submitted to a multiple case study. Initially this research was submitted as a proposal to conduct a survey considering the 18 existing ethanol production chains in the state of Goiás. However, some features related to the mills led to changes in the original proposal, which was redirected to a more restricted sample. It was decided to investigate large plants, located in the same region, and with the same manufacturing technology. It was discovered that there was a group of plants with a number of similarities. This group of plants originated at the same time, stimulated by a Brazilian national program called PróAlcool in the 70s. Thus, following these boundaries, a group of 3 plants was initially selected, with many similarities among them, and later a fourth plant was included. Three production chains were analyzed together with considerations at the same harvest period, which started in 2010 and ended in 2011. Subsequently, a new production chain was included in the analysis, considering the crop obtained in the period 2011/2012.

Research object

To attend its objectives, this research adopted a methodological approach based on multiple case study on supply chains plants located in Brazil, in the State of Goiás, one of the 26 Brazilian states, located in the Midwest region of the country and occupying an area of 340,112 km² (Seplan 2014). This state was chosen as the research object because it is an important producer of ethanol made from sugar cane, with the perspective of becoming in the next years, the largest global producer.

In the state of Goiás, until 2013, there were 33 sugarcane agro industries, producing around 40 million tons of sugar cane (Brazil’s 4th producer) and more than 2 billion liters of ethanol (Brazil’s 2th producer), employing directly and indirectly more than 100 thousand workers and occupying 400.000 hectares (1,15% of the state area) (Sifaeg 2013).

After the definition regarding the region of the Brazilian territory to be studied in this investigation, the research was headed for the selection of plants that were subjected to the multiple case study. After an extensive initial job of analyzing access to the data of companies with suitable profile to the requirements of the research, the full realization of this research was allowed in 4 plants, which in this article were denominated Plants 1, 2, 3 and 4.

Plant 1 was located in the center of the state and is considered large in size. It was created during the early stages of the program PróAlcool. The raw material was originated from leases of rural property contracts. There was the flexibility to produce sugar or ethanol in the mill. On the occasion of the research it was a family company, managed by the owners who were active
participants in the decision making processes in the organization. Plant 1 had a staff composed of permanent and temporary (seasonal workers) having on average 2,000 professionals.

Plant 2 also configured a large size organization, built with funds from of the PróAlcool program. Its production was exclusively intended for the manufacture of ethanol (meaning there was no sugar production at the mill). Through leases of rural property contracts, Plant 2 produced all the sugar cane consumed in its production process and did not relate to external suppliers of this commodity. It was set up as a family company, managed by the owners who were active participants in the decision making processes of the organization. At the time of conducting the research, Plant 2 had a staff composed of effective and seasonal workers, employing about 2,000 professionals in 2011.

Plant 3, located in the center of the state of Goiás, also considered as a large size organization, and was built during the beginning of the program PróAlcool. Its production was destined to the generation of ethanol and sugar. Through leases of rural property contracts, Plant 3 produced part of the sugar cane consumed in its production process (91,21 % of the whole demanding). The remaining raw material was obtained from external suppliers of cane.

Plant 4, located in the southwest of the state of Goiás, and was considered a large size organization. The raw material was acquired of properties belonging to the plant itself and external suppliers. Plant 4’s production was directed exclusively to the production of ethanol.

Research design

The research had an exploratory nature, turning, preliminarily, to search for information about the functioning of the supply chain, and later to analyze their constraints and propose improvements.

The survey covered the following steps:
- Literature review on the Theory of Constraints and management of supply chains;
- Research on the relationships existing between the links of the ethanol supply chain;
- Investigation on the existence of bottlenecks in the internal ethanol supply chain, through the quantitative analysis of data obtained from production reports used in plants to control their production processes.

Conceptual model

As a reference for analyzing the structure of the ethanol supply chain it was used for the basis of the conceptual model guidelines proposed by Hamacher et al. (2004), who had already served as a basic reference for the first stage of this research, previously developed by Machado and Borges (2008) and that, for reasons related to continuity of work, were once again adopted. This proposal presents an approach for managing the supply chain that is based on finding answers to the following questions: What influences the development of the supply chain? What are the organizations existing in the structure of the supply chain? What are the capabilities to produce and commercialize that each member of the supply chain has? What are the levels of integration and relationship of the members of the supply chain?

The supply chain study was divided into three stages. In the first instance it involved the identification, analysis, and comparison of organizations existing in the supply chain. In a second stage an approach for gathering and validating the data collected was determined. For this stage survey instruments were used such as, interviews, questionnaires, documental analysis and direct
observations. In a third and final moment, the data collected for each element of the supply chains adopted for the study were associated.

A delimitation of the reference model was proposed considering a focus on the internal structure of the manufacturing flow and involving, in detail, the steps of the production flow existing in the ethanol manufacturing plant. This delimitation of the model to the internal flow of the production came after examining the proposal Machado and Borges (2008) which suggested as a restrictive element of the supply chain the link of the machining operation of ethanol, which was confirmed by the qualitative investigation conducted in this research.

Figure 1 presents the model set as a reference for this research which was headed by Brito (2012) as the ethanol internal supply chain, comprising activities that arise in the production of sugar cane up to ethanol production.

![Internal Ethanol Supply Chain Diagram](image)

*Figure 1 - Reference model for analyzing the ethanol supply chain (Adapted from Brito 2012)*

It is noticed in the reference model presented in Figure 1 that the delimitation of the analysis became restricted to the action of the ethanol manufacturing plant, comprising from sugar cane production in the farms to the storage of finished product, going through the steps of cutting, loading, transport, processing and distillation.

**Presentations and analysis of data**

**Preliminary analysis of the supply chains**

For this analysis, interviews, and observations in the productive chains of the four plants adopted for the study were conducted. Representatives of the plants were interviewed separately, considering the people responsible for sugar cane production on farms, transportation of raw materials to the mills, and processing plants. In addition to the data obtained from the interviews, the technical facilities of the four plants were visited in order to check their premises and gather information about their production flows. A summary of the results obtained in this second phase of the investigation, referring to the productive chains of ethanol studied, is presented in Table 1:
In the three production chains analyzed presented in Table 1 there was unanimity among the respondents in each of them to affirm that the climatic factor was paramount to the production flow, since it generated uncertainty, influencing the quality of sugar cane, interfering with Total Recoverable Sugars (TRS), and, in cutting, loading and transportation activities. Therefore it was necessary to plan the sugar cane harvest to begin and end in the dry season.

Plant 4 did not provide all the information requested in the investigation and, therefore, results in its production chain were not confronted with the other results obtained in Plant 1, 2 and 3. However, some emerging information from the Plant 4 converged with the reality of the other plants while other informations were surprisingly divergent. This plant production processes were controlled in real time, with focus toward reducing losses caused by shutdowns in the processing, decreased rate of production, generation of waste and reduction of production flow. The raw material (sugar cane) was acquired from internal production or external suppliers as well as in Plant 3. Different from what was detected in the plants 1, 2 and 3, the main restriction encountered in the manufacturing process was located in the distillation stage (regarding the action in which the broth which is removed from the sugar cane passes through a heat, converts the liquid into a gaseous state, and then becomes liquid again, but in a more pure form).

Based on the foregoing, it was detected two major factors that directly had affected the supply chain: distillation capacity and financial capacity to invest. The price quoted for raw

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Plant 1</th>
<th>Plant 2</th>
<th>Plant 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production processes</td>
<td>Monitored</td>
<td>Monitored</td>
<td>Monitored</td>
</tr>
<tr>
<td>Production Control</td>
<td>Production flow management</td>
<td>Production flow management</td>
<td>Control of major production losses</td>
</tr>
<tr>
<td>Obtaining of the main raw material (sugar cane)</td>
<td>Produces all the raw material</td>
<td>Produces all the raw material</td>
<td>Produces and acquires raw material</td>
</tr>
<tr>
<td>Knowledge of the production goal of the company</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Knowledge of the goal of the company regarding the billing</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Restrictions (difficulties) influencing the company’s day-to-day operations in its production process</td>
<td>Cutting of sugar cane; storage of sugar cane cropped; loading and transportation; climatic conditions.</td>
<td>On the storage of sugar cane cropped; climatic conditions.</td>
<td>On the storage of sugar cane cropped; climatic conditions.</td>
</tr>
<tr>
<td>Restrictions found with regard to company policy</td>
<td>Lack of a regulatory policy</td>
<td>Financial problems due the high costs</td>
<td>Financial problems and difficulties to negotiate products</td>
</tr>
<tr>
<td>Link in the SC which defines the capacity of the production process</td>
<td>Grinding</td>
<td>Grinding</td>
<td>Grinding</td>
</tr>
<tr>
<td>Restrictions identified in the company's relationship with distribution channels</td>
<td>Financial factors, depending on the market values</td>
<td>Financial factors, depending on the negotiation</td>
<td>Financial factors, depending on the negotiations</td>
</tr>
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</table>
Material procurement, logistics and fulfillment of contracts accounted for complicating factors of the production system, related to producers or leaseholders. Regarding the distribution channels, companies came to the market through direct sales channels and the choice of these channels was made by analysis of the logistics system. The level of relationship with distribution channels was based on cooperation. Pricing policies were established by the market value. The commercialization of ethanol was defined by aspects such as demand, production and financial factors.

Returning to the joint analysis of the four plants studied, the grinding step was considered the bond that restricted the production of the internal ethanol supply chain. This statement was confirmed by additional analysis of records of bulletins of production, presented in the next section of this article. In Plants 1 and 3 significant evidence of the existence of bottlenecks in the transportation of sugar cane were identified, but the evidence was more strongly identified for the phase the sugarcane grinding. In the Plant 2 some evidences of the bottleneck of the internal production chain in the distillation stage were identified, but the most significant restriction was also shown in the grinding stage. In the Plant 4 the constraint was identified in the distillation step, but there was controversy regarding this data as the transportation and grinding steps were identified by some participants as restricting elements too.

**Quantitative analysis of the supply chains**

To confirm the identification of constraints in supply chains quantitative data collected daily from bulletins of production obtained in the plants subjected to the study were collected (only Plants 1, 2, and 3 provided these data).

The first study carried out was based on building a time series related to the volumes transported of sugar cane, as shown in Figure 2:

![Transportation of sugar cane in the Plants 1, 2 and 3](image)

*Figure 2: Transportation of sugar cane in the Plants 1, 2 and 3*

In figure 2, the nominal daily capacity limit of the transportation system of each plant was inserted for comparison with the volumes transported daily. It is possible to perceive in the analysis of Figure 2 that the volumes transported daily are approaching the limits of the capacity of each plant, but not beyond.

After performing the analysis of the transportation system, time series were constructed for the volumes of sugar cane grinded daily in each plant as shown in Figure 3. In this figure it was inserted for comparison with the amount of sugar cane grinded daily, the nominal daily capacity limit of the grinding system of each plant.
The analysis of Figure 3 provides a different conclusion from that observed in the analysis of Figure 2, regarding the use of capacity of the grinding (or sugar cane processing) system. In this figure it can be seen that the ground volume surpasses the regular system capacity at various times in the three plants analyzed. Moreover, in the other periods where it does not happen, the volumes grinds approach the limit of capacity of the plant. The final analysis was to verify the volumes of ethanol production in each plant. Figure 4 shows the time series obtained. In Figure 4 it was inserted for comparison with the amount of ethanol produced daily, the nominal daily capacity limit of the ethanol producing system of each plant.

In Figure 4 there is a significant gap between the volumes of ethanol produced and the maximum levels of existing productive capacity in each plant, with the exception of Plant 2. The quantities transported and ground and the processed volumes of ethanol are naturally coherent with each other, as they represent a productive system that reconciles their supply and production plans in accordance with their respective demands. But it becomes apparent in the analysis of the time series, the closer proximity to the quantities transported in relation to the quantities processed in the grinding stage (Figure 3), confirming the information initially obtained from preliminary analysis through interviews with managers of manufacturing plants investigated.

Concluding remarks

This research was conducted to map the structure of the ethanol supply chain in the state of Goiás in Brazil. Through the analysis and identification of the companies of this supply chain it was concluded that it can be summarized in four links: the production of sugar cane, the ethanol production, the ethanol distribution and the retail of fuel.

In its initial stage the research identified the bottleneck of the supply related to ethanol production (at the plant) stage chain. Later, in a more detailed analysis, it was detected that the
phase of grinding restricted the production flow of what was conventionally called in the research as the internal supply chain, being considered, consequently, the constraint of the whole supply chain.

Finally, the theory of constraints proved useful for analyzing the supply chain of ethanol, allowing for identification of the bottleneck of the system and discussing some proposals on this diagnosis of systemic improvements.

References


