Gest. Prod., São Carlos, v. 26, n. 3, e3446, 2019
https://doi.org/10.1590/0104-530X3446-19

Original Article

GESTÃO & PRODUÇÃO

ISSN 0104-530X (Print)
ISSN 1806-9649 (Online)

Analysis and proposal of reduction of lead time in the process of cutting, loading and transportation in a sugar cane factory: a study case

Análise e proposta de redução de lead time no processo de corte, carregamento e transporte de uma usina de cana-de-açúcar no estado de São Paulo: um estudo de caso

Larissa Diniz Freitas[1]
Thyago de Melo Duarte Borges[1]
Antonio Sérgio Martins[2]
Robertson Campelo Panaino[3]
João Batista Negrão Neto[1]
Moacir Godinho Filho[1]

How to cite: Freitas, L. D., Borges, T. M. D., Martins, A. S., Panaino, R. C., Negrão Neto, J. B., & Godinho Filho, M. (2019). Analysis and proposal of reduction of lead time in the process of cutting, loading and transportation in a sugar cane factory: a study case. *Gestão & Produção*, 26(3), e3446. https://doi.org/10.1590/0104-530X3446-19

Abstract: This article parts from the importance of sugarcane based energy to the Brazilian economy and, consequently, the important role of the process that involves cutting/loading/transportation (CLT) of cane in the supplies and production cost of sugar, alcohol and its derivates. For this purpose, a study case was carried in a sugarcane factory from São Paulo state, aiming to build a proposal that could reduce the lead time in the CLT process through the analysis of the Manufacturing Critical-Path Time (MCT) of the studied industry. With the data collected in the field visits, the MCT of one tone of sugarcane during its logistic process was done. This tool revealed a long waiting time of the cane waiting to be milled in the patio of the factory. Through the theory of dynamic of the systems it was concluded that this time was high due to the variability of the field as a consequence of an inefficient use of the harvester and the logistic system of dynamic allocation of the transportation resources ahead in the harvest. To make the harvester more efficient, a reduction of 40% of the laying time "awaiting transshipment" was proposed, which would result in a save of R$ 1.172.784,00/year. For this reduction five proposals were identified to be implemented in parallel: integration of the systems of the board computer and the traffic control system; integration of the board computers of the harvester and the transports; implementation of truck filling volume sensors; focus in the management of basis leaders; and, implementation of a multitask worker.

Keywords: Logistics; Production management; Quick response manufacturing.

Resumo: *A partir da importância do setor sucroenergético para a economia brasileira, e da importância do processo de corte/carregamento/transporte (CCT) de cana no suprimento e no custo da produção do açúcar, álcool e derivados, este artigo tem como estudo de caso uma usina de cana-de-açúcar paulista. O objetivo deste trabalho foi construir propostas de redução do lead time do processo CCT de cana-de-açúcar, através da análise do Manufacturing Critical-Path Time (MCT) da usina estudada. Com os dados coletados nas visitas à campo, foi feito o MCT de uma tonelada de cana ao longo de seu processo logístico. Essa ferramenta apontou para o grande tempo de espera da cana aguardando para ser moída no pátio da usina. Por intermédio da teoria da dinâmica dos sistemas, concluiu-se que esse tempo era alto decorrente da variabilidade no campo, consequência*

[1] Departamento de Engenharia de Produção, Universidade Federal de São Carlos (UFSCar), Rodovia Washington Luís, km 235 – SP-310, CEP: 13565-905, São Carlos, SP, Brasil, e-mail: lari_diniz@hotmail.com; tmdborges@gmail.com; jbnneto@yahoo.com.br; moacir@dep.ufscar.br

[2] Curso de Administração de Empresas, Faculdade TREVISAN Escola de Negócios, Av. Padre Antônio José dos Santos, 1530, CEP: 04563-004, São Paulo, SP, Brasil, e-mail: antonio.sergio.martins@hotmail.com

[3] Centro Universitário Adventista de São Paulo – UNASP, Estrada Municipal Pastor Walter Boger, S/N - Lagoa Bonita, CEP: 13165-970, Eng. Coelho, SP, Brasil, e-mail: robertson.panaino@ucb.org.br

Received Sept. 10, 2017 - Accepted May 28, 2018

Financial support: None.

da ineficiência do uso da colhedora e do sistema logístico de alocação dinâmica dos recursos de transporte nas frentes de colheita. Para melhorar a eficiência da colhedora, foi proposto uma redução de 40% de seu tempo de parada por "aguardando transbordo", que resultaria em uma economia de R$1.172.784,00/ano. Para realizar essa redução, foram identificadas cinco propostas a serem implementadas em paralelo: integração dos sistemas de computador de bordo e o sistema do controlador de tráfego; integração dos computadores de bordo da colhedora e dos transbordos; implementação de sensores de volume de preenchimento da julieta; foco na gestão dos líderes de frente; e, implementação do trabalhador multifuncional.

Palavras-chaves: *Gerência da produção; Logística; Quick response manufacturing.*

1 Introduction

The business context gets more globalized every day, and the organizations cannot be competitive without an efficient planning of their productive processes and an offering of qualified products and services to the clients in an as-short-as-possible processing and delivery time. That is the main reason why it is important that companies invest in the reduction of their lead times, because this would bring to the companies a lessening in the costs of operation and quality, eliminating processes that do not aggregate value to the product or bring more satisfaction to the clients.

This is the perspective that the Quick Response Manufacturing (QRM) philosophy defends. According to Suri (2010), the QRM is characterized by a business strategy which's main goal is to reduce the lead time in all operational aspects of the company, both internally and externally. Thus, this strategy aims to answer the demands of the clients by planning and processing quickly the necessity of the consumers.

The QRM is constituted of guidelines that can be applied to any type of company, either manufacturing, services, or a combination of both. Parting from this versatility the QRM, it can also be applied to companies that work with agricultural compounds, such as the sugarcane production. According to the Brazilian Company of Supplies (CONAB, 2016), its production in the 2015/2016 harvest was estimated in 658.7 million tons, revealing a 3.8% growth in relation to the past harvest. However, the production of sugar was estimated in 34.6 millions of tons, which shows a reduction of 2.7% in relation to the previous harvest, and the ethanol production was estimated in 2.9 billions of liters, a raise of 1.9% in relation to 2014/2015.

Again according to CONAB (2016), one might notice that Brazil is the biggest producer of sugarcane in the world, and São Paulo state has the biggest production in the country, summing 52% of the sugarcane hectares, followed by Goiás state with 10.1%. The GDP of the sector is of R$ 28.15 billion, which represents 2% of the total GDP of the country (Neves & Trombin, 2014).

Many types of process happen in the factory since the plantation of the sugarcane crops, the harvest and the logistics of the supplies, until the production of the final products (sugar and ethanol). But one of these processes must be highlighted by the agricultural managers: the cutting, loading and transportation of the sugarcane from the crops to the factory. According to PECEGE (2012), these operations correspond to about 40% of the costs of all the cane process.

Considering the importance of the sugar energy sector to the Brazilian economy, and particularly the importance of the process of cutting/ loading/ transporting (CLT) of cane in the supplies and production cost of the final products in a company of the sector, this article held a study case in a sugarcane factory located in São Paulo state. It intends to analyze the processes of harvesting in the studied company and to find solutions that might make it more efficient, parting from the reduction of the lead time through the QRM approach. Thus, the aim of this article is to build proposals of reduction of the lead time in the process of cutting, loading and transportation of sugarcane, using the analysis of the Manufacturing Critical Path Time (MCT) of a factory in São Paulo. In this sense, the QRM theory will be even more consolidated in the process under different conditions from those previously tested, and also promoting a tool to optimize the sector that represents approximately 2% of the Brazilian GDP.

This article is structured as it follows: chapters 2 and 3 bring a brief literature review on QRW theory and the process of cutting, loading and transportation (CLT) of sugarcane, respectively; chapter 4 explains the research method used and the proceedings carried during the study case; chapter 5 than registers the analysis of the studied case and the appointing of solution proposals to the problems found; finally, the last chapter brings the conclusion of the work.

2 Quick Response Manufacturing (QRM)

One of the most relevant factors in production administration consists in the management of time, hence highlighting the administration of the lead time production. According to Lima et al. (2013), the reduction of lead time is in an important competitive advantage. To Borja et al. (2018) the variability of the lead time affects the company's efficiency, both in internal aspects and in terms of the supply chains.

This research takes use of the definition of lead time presented by Ericksen et al. (2007) in which time is counted in calendar days, beginning with the clients request, passing by the critical path of the productive process, until the first piece of the order is produced and delivered to the client. Other relevant works also use this definition, such as Severino et al. (2010) and Uzsoy (2010).

In the view of Saes & Godinho (2011), due to the importance of lead time for the production management, a series of approaches concentrates its studies in ways to reduce the lead time, highlighting the Lean Manufacturing, the Time Based Competition, and the Quick Response Manufacturing. The QRM deserves special attention because it is focused only in the reduction of lead time.

The QRM was proposed in 1998, in the USA, by Rajan Suri, aiming to reach the reduction of lead time in environments with a high variety of products. According to the studies that have been developed by the QRM research center and its partners, when the principles and techniques of QRM are applied there are relevant reductions on the lead time. These reductions reach about 80% in the new products the introduction time and also raise the market share of the company in 42% (Suri, 2010).

According to Lima et al. (2013), the reduction of lead time occurs due to the implantation of a project that needs to follow an specific method composed by four steps: definition of the problem; data collection and analysis; optimization proposals using principals and techniques of QRM; and, analysis of the expected results. Suri (2010) states that certain techniques help in this implementation process, such as process mapping, tagging, graphics of the aggregate values, simulation and modelling of the capacity, tools of TQM, brainstorming, simple statistics tools and system dynamics.

Continuing in the approach of Suri (2010), QRM is divided in 10 principles. The first of them is the importance of finding a completely new method for the works to be done, focusing in the reduction of lead time. The second principle emphasizes the planning of the critical resources capacity in 70% or 80%. Third principle discusses the reduction of lead time as the most important performance measure. The fourth alerts to measure and reward the reductions of lead time instead of the deliveries accomplished in the promised time. The fifth principle suggests the use of MRP (Material Requirements Planning) as a support to the planning of high level materials.

Suri (2010) continues listing and explaining these 10 principles affirming that the sixth topic aims to motivate the suppliers to implant the QRM, while the seventh alerts the importance of clients understanding the paradigm of this tool. The eighth describes the elimination of functional barriers due to the implantation of cells. The ninth principle's objective is to show all moments in the company chain that time must be reduced so that a successful organization can be created in long term. Finally, the last principle defends the training of the company workers aiming a whole change of thought.

One of the techniques most commonly defended by QRM consists in the development of a tool denominated Manufacturing Critical – Path Time (MCT). The term MCT was proposed by Ericksen et al. (2007) and represents basically the lead time under the view of QRM. For these authors the MCT is built in the observation of an only product during the lead time. It is counted from the emission of an order, which passes by a critical path, and ends when the first piece is delivered to the final consumer. For Suri (2010), the MCT can be represented in a graphic that the shows the proportion of the time spent between activities that do aggregate value to the product, and those activities that do not. According to the same author, this graphic can also show the activities that do not aggregate value but are necessary. As it is seen in Figure 1, time required by the activities that aggregate value is colored in light gray, and the activities that do not aggregate value are on a hatched pattern.

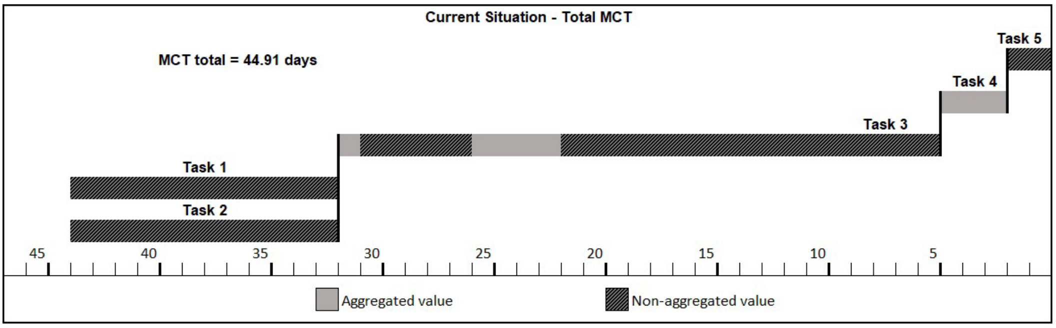


Figure 1. Representation of an MCT.
Source: Adapted of Ericksen et al. (2007).

The time spent in processes that aggregate value is called by Suri (2010) *touch time*, referring to the exact time in which a fundamental process with aggregated value needs to be finished. The author states that the touch time represents less than 5% of all the lead time, meaning all the rest of the time is spent in activities that do not aggregate any value to the product.

Time beyond touch time, in other words, that does not aggregate value, either because it is spent in unnecessary processes, waiting or any other reason, is called *idle time* or waiting time by Suri (2010). The idle time usually represents around 75% to 95% of the lead time and it is in this time that measures are concentrated for the reduction of waiting time.

When touch time and idle time are put together we have the complete lead time and thus the MCT is built in "calendar time", in other words, counted in days, because according to Ericksen et al. (2007) that is how the clients see the time they are waiting for the product. Hence, this is how it is possible to represent the process graphically, simplifying the analysis and making it more precise to determine the processes that must be altered or optimized.

Once the operations that least aggregate value to the process are identified, which means, are wasting more time, it is necessary to evaluate the causes and propose optimization actions. To find the causes one must consider the dynamic behavior of the systems. According to Wu et al. (2010), the dynamic of systems uses internal feedbacks and time delays that affect the behavior of the whole system.

3 Cutting, Loading and Transportation Process (CLT) of the sugarcane

The cane industry grows constantly. The demands for sugar, alcohol and derivatives increase the processing of the volume of feedstock, requiring a considerable allocation of workers, equipment, logistic services and an efficient management that can guarantee the execution of the activities in this chain (Scheidl & Simon, 2012).These logistic systems are fundamental to the operational efficiency of the factories, because they act in the integration of agricultural and industrial operations, aiming to determine the best time in the process of cutting, loading and transporting the sugarcane [CLT process] (Meurer & Lobo, 2015).

This processed volume growth results in many increases for the for the agricultural logistic of the CLT, like the use of harvesters, tractors, transportation, trucks and implements, not counting the supporting vehicles, such as train-truck, water truck, workshop-truck. Such situation also points to a growing complexity in the relations and synchrony necessary between the activities (Scheidl & Simon, 2012), not forgetting the main challenge of maintaining the factory in constant operation, with no idleness and counting the cane stocks as close as possible to zero (Meurer & Lobo, 2015).

The State Law n.11.241/02, (São Paulo, 2002) enacted the establishing of a plan for the progressive elimination of cane plantation burning as a shredding method – the deadline for the end of this method was until year 2021 in mechanized fields or possible to be, and until year 2031 for fields not possible to be mechanized. This plan was anticipated in 2007 by the Agro-environmental Protocol of the Sugar Energy Sector of São Paulo, accorded between the São Paulo state government and the Sugar Energy Sector, putting end to the burning of cane plantations in 2014 for mechanized fields and in 2017 for not-mechanized fields. Though it is not a law, this document was put in practice by 86% of the industries and 27 associations of suppliers in São Paulo state (São Paulo, 2014).

Due to these agreements, the mechanized harvest was adopted in an accelerate process by the factories (CTC, 2014). The Agro-environmental Protocol (São Paulo, 2014) points to a considerable growth in the acquisition made by its signatories of their own harvesters, rising from 917 harvesters in 2007/2008 to 2.856 in 2013/2014.

With the raise in the mechanization of the harvest and, consequently, the increase in the volume of the processed feedstock, the level of operational efficiency became a lot relevant to the operational costs. Also, knowing that the chopped cane quickly suffers degradation and thus cannot have high stocks, inefficiencies in the CLT process are highly harmful both to the quality of the sugarcane and to the production cost (Scheidl & Simon, 2012). The complexity and the variable amount in the question demand strict planning and a strategy of management and support with constant monitoring to assure the harmony in the system and uninterrupted income of cane supplies in the factory (Meurer & Lobo, 2015).

In this plan one should consider the origins of the sugarcane, which means, the location of the basis of cutting and loading (these bases are constituted of groups of productive resources that operate the cane harvest in some planting areas), the proceeding of the harvest and several types of equipment involved (Meurer & Lobo, 2015). The volume of cane to be transported to the factory varies according to the environmental conditions (climate, basis location, types of the road and route specifications).

Another relevant concern to the logistic managers are trucks stopped in traffic, especially considering the cost of the investment, the fuel cost, the laborers and how much these vehicles are missed in the fields (Meurer & Lobo, 2015). According to a study case done by Zuquette et al. (2015) in an important rectory of the field, the critical factors contributing for the lack of sugarcane in the factory were the low availability of the harvesting equipment and the lack of transportation, pointing to the importance of the management of these resources.

In this scenario Scheidl & Simon (2012) justify that the sugarcane factories are potential clients to outsourcing logistic services, since once a company establishes partnerships with a logistic operator it centers its striving in its core business and is exempted from making great investments in logistic equipment.

Another way to ease the logistic management in such a way to grant that the supplements of cane will be distributed during the day to the factory with minimal feedstock stocks as possible is to adopt softwares that indicate the best decision to be made in the most different scenarios. Many authors (Rangel et al., 2009; Lazzarini et al., 2010; Silva et al., 2011) appeal to the modeling and simulation of sugarcane energy agricultural and industrial process to assist the decisions to be made in its logistics. Other softwares constantly simulate the progress of the activities, using a GPS to follow each vehicle involved in the CLT process (Meurer & Lobo, 2015).

An example of how these softwares contribute is seen in the work of Dourado et al. (2014). These authors realize that a study about mechanized harvest is monitored by board computers. They analyze computer data referent to one month in the harvest of the 2013/2014 crops done by a harvester. Observing the collected data 60% of the harvester's operation time was used in the harvest, 22,4% in maintenance, in 10,1% of the time the machine was stopped due to rain, and in 7,5% of the time it was stopped for other reasons. Based in the data collection, the harvest basis leaders or the managers verify the reasons for the low availability of its equipment and make decisions to improve this situation, for example.

4 Research method

Before detailing the method used in this research it is important to highlight that this article resulted from a study case carried in a sugarcane industry located in São Paulo state. In the conception of Yin (2015) the study case method's main aim is to investigate a contemporary phenomenon defined as the "case" parting from its real life context, emphasizing that this occurs especially when the limits between the phenomenon and the context are not clearly defined.

Once we have outlined the definition of study case it is necessary to describe the sequence used by the research to reach the goal proposed by this article, thus characterizing the research method, which was defined in 5 different stages. The first consists in the development of a bibliographical review, deepening the knowledge of pertinent themes to the research, relating and discussing the theories and practices of the QRM literature, also clarifying the concepts inherent to the tools used in the study case.

In the second stage of the method the researchers defined the scope of the developed project based on non-structured interviews with relevant people from different parts of the process like: one of the logistic consultants of the studied factory, the moto-mechanization manager, the traffic operator, the basis leaders, and the drivers of the trucks and harvesters. The moto-mechanization manager was the main source of the information, because besides his experience as manager in this field he had professional experience in all other sub-areas of this management.

We should emphasize three visits to the field and consultations to documents offered by the organization, mostly related to the history of the stopping of equipment (harvesters and transshipments) in the fields and to analysis of the harvest productivity in the basis. Hence, it was defined that the focus of the project was laid in the reduction of the lead time in the processes of cutting, loading and transporting sugarcane, leaving the industrial process of the factory as a black box due to the unavailability of access given to the researchers.

For better understanding the process (1st visit) a general flow chart was built gathering the macro processes, as the following: systematization of the harvest areas, preparation of the soil, planting, harvesting, transportation and factory. Still in this stage of the method an activity plan was developed including dates of meetings of the researchers, dates for technical visits, creation of flow charts, data collection, development of improvement solutions, simulations and improvement plans. It was in this phase of the method that the MCT was built helping the team to understand the processes that demand more production time.

The third stage consists in the accomplishment of the detailing of the processes involved in the harvesting, loading and transportation of the sugarcane. For this purpose, a second visit to the company was happened objectifying mainly to execute the QRM detective technique. According to Suri (1998) this technique consists in searching for and finding opportunities of improvement aiming to find the root cause of the problem.

In this sense, this work focused in finding the tasks that took more time to be accomplished; the locals with longer delays and the reason for those delays; also, discovering which tasks add value and which ones were unnecessary building a flow chart of the focused progress. After the visit, problems and possible improvement opportunities were listed.

The fourth stage consisted in the creation of a flow chart focused in the processes that most spent time. Like this it was possible to realize a better definition of the problems and consequently the construction of an improvement plan. This plan focused its attention a group of alternative options that had the solution for that a certain problem, the benefits and quantified costs of the solutions, improvement impacts and possible obstacles in the implantation of the proposals. The fifth and last stage (3rd visit) consisted in the presentation of these proposals to the representatives of the studied company.

The solutions obtained and presented in the fourth and fifth stages of the process are founded in the MCT theories (Ericksen et al., 2007) and QRM detective (Suri, 1998), as well as in the professional experiences of the authors of this text.

Pictures and videos were registered during the technical visits of the agricultural process of harvesting and loading of the sugarcane in one of the basis of the factory. Data of the periods of previous harvests and the current harvest were also collected from the board computers of the agricultural equipment to verify the time spent in activities and stops during the CLT process. These photographic and video records during the factory visit were authorized by the moto-mechanization manager responsible for accompanying visits to the company. On the other hand, equipment data was collected by factory professionals and sent to participants of this project via e-mail.

4.1. The study case

As it was mentioned previously, the sugarcane factory studied belongs to a group of the sugarcane energy sector, located in the north region of São Paulo state. Nowadays this factory mills 3.800.000 tons of cane per year, owning 6 harvest basis (100% mechanized), counting with 20 harvesters, 32 tractors for pulling transshipments and 34 trucks responsible for the transportation of cane from the basis to the factory.

The structural organization of the company is shown in Figure 2. In the first level is the unit manager, responsible for the whole blueprint of the unit. This unit, in its turn, is divided in agricultural and industrial fields, each of them with their respective managers. The agricultural manager coordinates the managing of the preparation, treatment and fertilization-irrigation of the automotive workshop and of the moto-mechanization. This last past is subdivided in the following sectors: harvest, transportation and traffic control. The harvest manager is responsible for the basis leaders, that monitor and control the operators of harvesting and transshipment, the mechanics, the fireman and convoy people. The transportation manager coordinates the cane plantation drivers and patio leaders.

In Figure 3 the general flow chart represents the agricultural processes until transportation of the feedstock into the final product. First the systematization of the crops is accomplished with drawings and dimensions

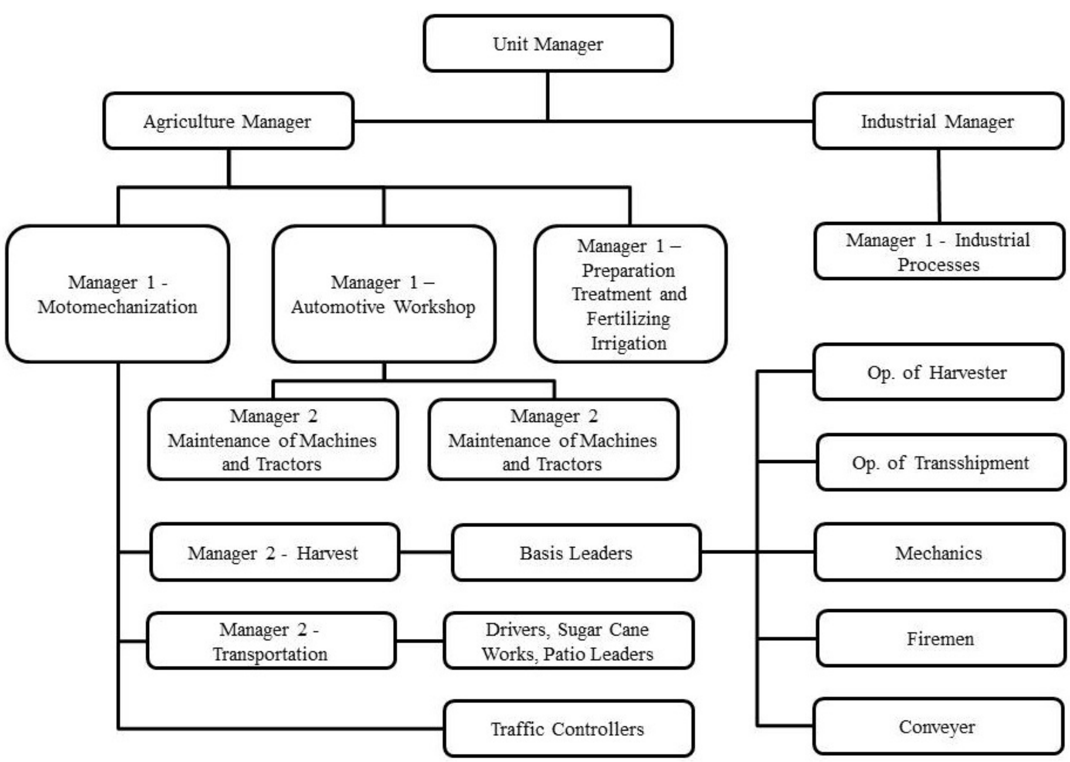


Figure 2. Organizational structure of the studied factory.
Source: Elaborated by the authors.

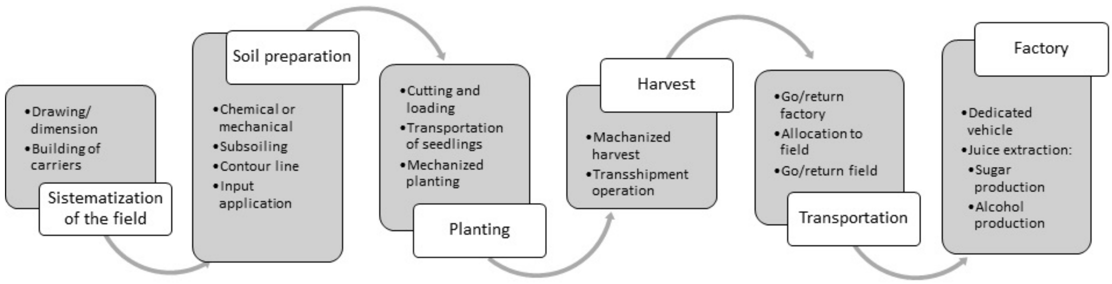


Figure 3. Flow chart of agricultural processes until the final product.
Source: Elaborated by authors.

of the blocks in the territory and the construction of roads for vehicles to be driven through the agricultural area. After the systematization of the area the soil is prepared by the mechanization or chemical eradication of residues derived from the plantation in previous harvests, subsoiling, construction of the level curve and finishing touch, and finally the application of agricultural inputs. The next step is plantation.

Depending on the cane variety, after 12 or 18 months the harvest happens. In this factory the harvest is 100% mechanized. The harvester cuts the cane and lays it upon two transshipments drawn by tractors. After being filled they go to an area called “malhador” (The name was maintained in Portuguese, since there was no equal translation, and also to keep the originality once it is a name give by the factory workers – it refers to the place in the fields were the cut sugarcane unloads and is placed in other transportations, as it will be explained along the text.) and unload in the next “juliets” (Juliets are bigger trucks that can load up to 4 or 5 tons of sugarcane. Most cane factories call this specific truck that way, so the original name was kept here, translating “julieta” (respective name in Portuguese) into “juliet”.) parked there. These loaded “juliets” are transported through trucks unto the patio of the factory, where they are released and summed to the cane stocks to be milled. After the milling, the generated cane extract will be transformed into the final products: sugar and ethanol.

The harvesters, tractors and trucks have board computers imbued with technologies focused in monitoring the efficiency and pauses of these equipments.

4.2 MCT survey of the CLT sugarcane process

Once in power of the data collected from the fields, it was possible to accomplish the MCT (Figure 4). For this, one tone of cane harvested in the field was taken as an analysis unit and was monitored, so that the time from the field to the factory would be counted, following this sequence:

a) Harvester: cutting the cane unit, estimated in 2 minutes, in which 1 minute referred to the act of cutting the cane and 1 minute corresponded to the pauses of the harvester;

b) Transships: the time spent to fill both transships carried by the tractor;

c) Transshipment: transship lays the harvested mass in the “juliets” in the field of the “malhador”;

d) Waiting time of the truck in the field: time for two “juliets” to be filled;

e) Transportation to the factory: truck transports two filled “juliets” to the factory;

f) Weighing/ sampling: time to weigh and take a sample of the truck that arrived in the factory;

g) “juliet” waiting to come-and-go: time that the “juliet” composes the cane stock in the patio;

h) Transport to the milling: time that the dedicated vehicle (called come-and-go) takes to transport a filled “juliet” from the patio to the mills;

i) Factory: processing of the tone of cane, treated as the “black-box” in this work.

Observing Figure 4 the longest waiting time for the cane in the CLT process is the stocking in the patio of the factory, represented in the figure by the item “juliet” waiting for the “come-and-go”.

The time (size) of the feedstock stock in the patio desired by the factory is of 1 and a half hour for the milling. The factory mills 18.00 tones, which makes 750 milled tones per hour. Considering that a truck is able to transport 70 tones in each trip, we conclude that the factory mills 10,7 groups of loads per hour. Thus, the desired stock is of 16 groups of loads for 1 and a half hour of milling.

However, what is seen in practice is a stock of approximately 2 hours of cane that results in a stock of 20 groups of loads (“juliets”).

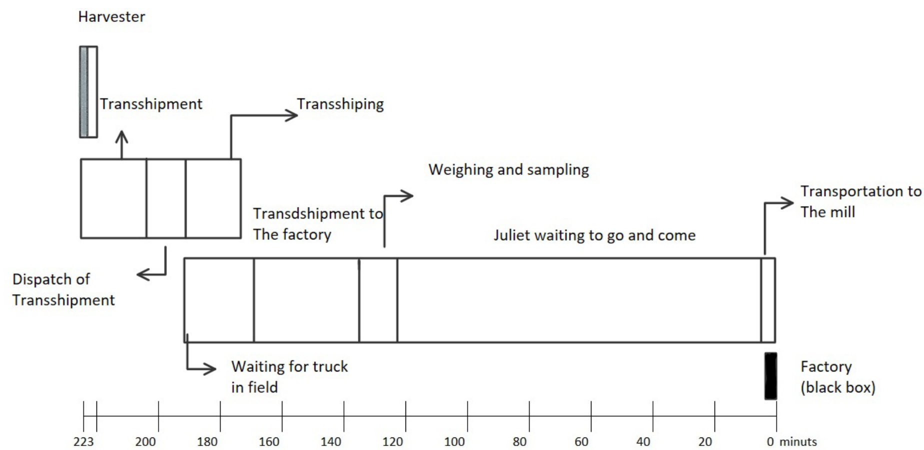


Figure 4. MCT of the studied agricultural process.
Source: Elaborated by authors.

4.3 Survey of root causes during the waiting time pointed by the MCT

For each item considered in the MCT root causes of waiting time were investigated through the QRM detective strategy (Annex 1). The main conclusion obtained was about the need of the current stock size: due to the high variability of the cane harvesting process there is an increase in the risk of a lack of cane provisions in the factory; so, to diminish this risk the stock should increase.

Aside from the environmental and geographical variables inherent to these process there is also an operational variability that is higher or lower depending on the management of the cane transportation from the field to the factory.

In the factory selected for this study the management is mediated by a dynamic allocation system of transshipments and tracks in the basis of the harvest (Figure 5). At the basis, the leader determines where the harvesters should be allocated in their working field, according to the production daily quota attributed by the moto-mechanization manager. Depending on the location of the harvesters in relation to the "malhador" of the basis the time cycle of the tractors (time between when the tractor leaves the "malhador" to the harvester, added to the time of loading the transshipments, plus the time back to the "malhador") increases or decreases, determining the basis production rate.

At the "malhador" the transshipments pulled by the tractors carry the "juliets" that, in the best of possibilities, are transported right away to the factory. It is in this moment that the truck allocation happens.

The leader informs the traffic controller the production rate of his basis (calculated by the time cycles of the tractors), and the controller, on its hand, allocates the trucks to the fronts that are holding the loads ready to be consolidated, respecting the time cycle of the trucks (time the truck takes to go to the field, plus the time it takes to go back to the factory). In this sense, the moments of complete loading of the "juliet" in the "malhador" and the arrival of the truck in the basis should be coincidental in such a way that an efficient usage of the resources happens and guarantees the supplement of the cane stocks constantly. However, observing this process practically, these moments do not agree in most of the times due to a series of problems generated by flaws in the management by the leader in field, or because of problems in the communication between the front leader and the traffic controller.

The problem with the logistic grows when we add variables such as: the time spent in the dislocation of the trucks in a radius up to 46Km, which is the distance of the farthest basis to the factory; the use of road transportation, which implies limitations in weight and size of the vehicles (the maximum length permitted is 30 meters); the low quality of the roads from the basis to the factory, some of them have many unpaved and narrow parts.

Though they are not explicitly shown in the MCT, transshipment and harvester are two sources of variables in the process, once their availability in the production float along the days and consequently, depending on the harvest season. Figure 6 reveals the average behavior of a harvester, a tractor and a truck during a day, based on the analysis of historical data of the board computers of these resources in a factory basis during one month. The harvester worked, in this case, 15 hours in the cane crops, but would be stopped for 9 hours. The reasons of the pauses, in importance order, were: logistic problems, mostly lack of transshipment (while waiting for their arrival); maintenance issues; and, finally, climatic problems. For the tractors and trucks the biggest problem that

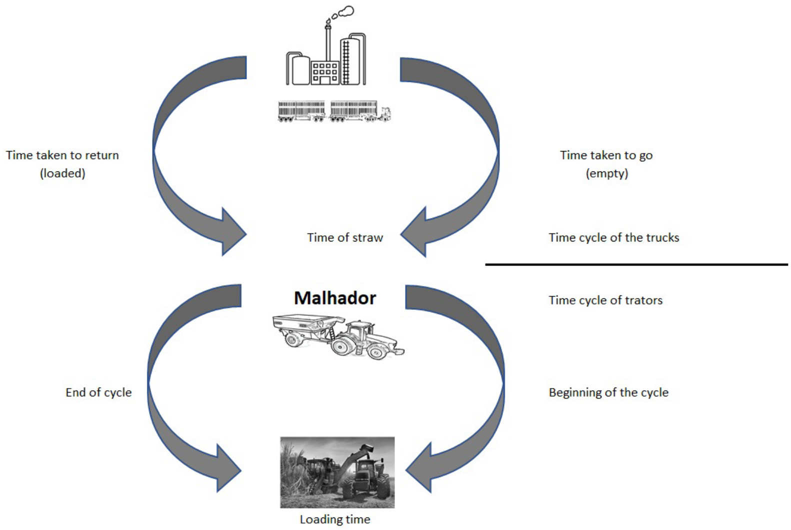
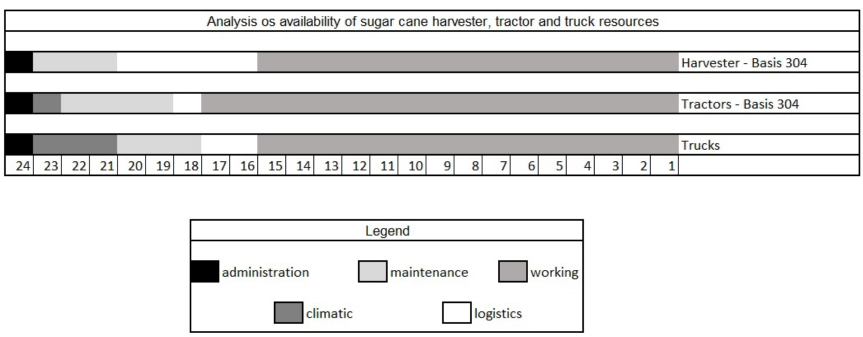


Figure 5. Process of dynamic allocation of the transshipments and trucks in the harvest basis.
Source: Project documents.



Group	Description of the current operation	Sum of duration
Logistics	Waiting for transshipment	230:02:57
Logistics	Waiting for orders	35:30:56
Logistics	Waiting for trucks	26:03:10
Logistics	Change of area	25:15:05
Logistics	Carrier displacement	07:35:14
Logistics	Waiting for train	00:29:10
Logistics	Loading / unloading machines	00:05:18

Figure 6. Analysis of the availability of the harvester, tractor and truck.
Source: Elaborated by authors.

occasion a pause was due to the maintenance, and in the truck's case, administrative problems.

5 Analysis of the case and proposal of sollution for the problems

Analyzing the MCT we could see that the stock in the patio of the factory derived from the variability in the field, which is a consequence of an inefficient operation of the harvester and the logistic system of dynamic allocation of sugarcane transportation resources.

Parting from an attempt of improving the harvester, we propose a reduction of 40% of the time the machine is paused "waiting for transshipment" of the harvester, resulting in an economy of R$ 1,172,784.00 per year. This value was calculated based on data from the board computers of the 20 harvesters of the factory in May 2016. The results of the calculations are shown in Table 1.

First, we filtered the sum of the time spent by the 20 harvesters waiting for transshipment. Then, 20% of this total was calculated representing what would be available for production after the improvement actions of this reduction. Once having these 1,120 literal hours extra in the production, 20 more hours for fueling, 189 hours in maintenance, and 50 more hours in other operations that depend on the displacement of the harvester. If we gather all discounts, there would be 14,480 extra hours available for the harvest.

Table 1. Calculation of save when a 40% reduction is done in the harvester time "waiting for transshipment".

Time waiting for transshipment (WT)	2790	hours/month
Total of machines	20	units
Average time per machine WT	140	hours/machine/month
40% of the average time by machine in WT	56	hours/machine/month
Extra time in the harvest with the 40% reduction	1120	literal hours total
Discount for fueling	20	hour
Discount for maintenance	189	hour
Other discounts	50	hours
Extra time of harvest with the 40% reduction	861	hours
	10.75%	extra worked hours
Maximum worked hours	14880	total hours/month
Current efficiency	54%	
Current inefficiency	46%	
Efficiency (reducing 40% of the WT)	60%	
Inefficiency (reducing 40% of th WT)	40%	
Inefficiency	Income (ton/day)	Cost (R$/ton)
34.90%	500	6.54
40%	461	7
46%	415	7.53
47.90%	400	7.71
Daily saving per harvester	244.33	R$/day/harvester
Monthly saving per harvester	7329.9	R$/month/harvester
Total monthly saving	146598	R$/month
Total year saving	1172784	R$/year

Source: Elaborated by authors

Because of this increase, the efficiency of the harvest would go from 54% to 60%, leading to a save of 53 cents in each processed tone (based on a table of costs *versus* efficiency of the harvest offered by the factory). Applying this save and multiplying it by the number of harvesters in each days and months during the harvest we get to a save of R$ 1,172,784.00 per year.

Furthermore, a 15% improvement in the efficiency of the process would make possible the reduction of the stock from 1,9h to 1,5h, according to the professional experience of the moto-mechanization manager. Based on this information we can also conclude that in a case of a 6% change in the efficiency of the harvester it is possible to estimate a reduction from 1,9h to 1,74h in the future situation stock, which means a reduction of 8,43% of the cane in the patio.

To accomplish the proposed improvement of the 40% reduction in the time spent while "waiting for transshipment" of the harvester five proposals to be implemented alongside were identified and will be described.

5.1 Proposal 1: Integration of the board computer systems and Logtrac system

LOGTRAC is the logistic system used by the factory for the control of truck dynamic allocation traffic in the transportation of sugarcane from the factory to the harvest basis and vice-versa.

Nowadays the integration of these systems (LOGTRAC and the board computer system) is done manually under the management of the basis leader that takes care of the time cycle of the transshipment and informs to the traffic controller the production rate in that basis (calculated according to the time cycle of the tractors). The controller, in its turn, allocates the trucks directing them to the basis that are loaded near to consolidation, respecting the time cycle of the trucks (time to go to the field and the time back to the factory).

The integration of these systems would automate the ordaining in the line for the allocation of the transshipments and synchronize it with the dynamic allocation of the trucks. This integration would be developed through the access to the data dictionary of the board computer, calculating precisely the filling up of the transshipments and optimizing the dynamic allocation time of the trucks.

5.2 Proposal 2: Integration of the board computer of the harvester and of the board computer of the transshipment

The integration of the board computers of the harvesters and transshipments through the data dictionaries would automate the communication of these two types of vehicles in the harvest basis, permitting an optimization in the allocation of the transshipments, and thus reducing the time spent by the harvester "waiting for transshipment" and even reducing the number of transshipments needed in the basis. Such integration as proposed would be done by LOGTRAC.

There is a software in the market of SOLINFITEC company called Transshipment Only Line ("Fila Única de Transbordo") which can build an example of this integration. According to its developer, this software "organizes automatically a line of transshipments in the 'malhador' to attend the harvesters that need a new transshipment" (Organiza de forma automática uma fila de transbordos no malhador para atenderem as colhedoras que necessitarem de um novo transbordo) (SOLINFTEC, 2014, translated by author).

5.3 Proposal 3: Volume sensor for filled "Juliets" and automatic dispatch of this signal to traffic control

The placement of volume sensors that would warn that a "juliet" has been filled with indications as "loading begun", "50% loaded" and "100% loaded", as well as an automatic dispatch of these information to LOGTRAC would allow an optimization in the truck sending to the collection of the filled "juliets" and making empty ones available leading to a better use of the trucks and transshipments, consequently reaching a better use of the harvesters.

5.4 Proposal 4: People management – basis leaders

This proposal is based in the constant realization of training in the beginning of the harvest along with the basis leaders, aiming to enable them in the best way possible in the matter of managing a harvest basis.

This training is important to formalize which are the activities, responsibilities and proceedings to be done along the harvest basis and its workers. Some functions of the leaders are: to know how to act according to the variables that influence in the efficiency of the harvest basis; know how to calculate the time cycle of the transshipments inside the basis; and to know the daily production capacity of the harvest. Another important point in this training is the communication between the leader and his workers, as well as with the traffic control.

Although this training is already happening in the factory through a hired consultant for this purpose, it is possible to identify that this should be continually improved due to the high turnover of the functions inside the harvest basis. Basically, these workers are hired in the beginning of the harvest and dismissed at the end of it.

Another important point to be fulfilled by the basis manager is to hold a meeting at the end of the harvest aiming to identify the lessons learned from the management. Questions like which items were improved in relation to the previous harvest and which opportunities of improvement were identified to be implanted in the next harvest. Aside from these trainings the supervision and advising of the harvest manager along with the leaders are fundamental for the success and improvement of the CLT process.

5.5 Proposal 5: Multifunctional worker

This proposal consists in adding a new function inside the harvest basis – an assistant that can act helping to substitute different functions. This assistant in the harvest basis would work in various positions, such as replacing the harvester operator, the transshipment operator, or even work as a mechanic assistant. Therefore, if one professional is absent this assistant can cover the unfilled function.

Another proposal to be implanted could be the utilization of the best professionals identified by the factory to be maintenance assistants during the period between the harvests. Besides allowing the reduction of the turn-over and professional motivation, during this time the referred worker would enlarge the maintenance in the equipment he operates making unnecessary to wait for a mechanic's assistance in the damaged equipment. This alternative has been put in practice in Australia proving itself efficient (Narimoto, 2015).

If these five proposals are implanted, we expect to attain the goal of reducing around 40% of the time waiting for transshipment, improving the lead time in the process of cutting, loading and transportation in a sugarcane factory. This goal can be measured through the board computer data, comparing the averages of the "time waiting for transportation" before the implantation of these proposals with the same averages after these strategies will have been put in practice.

6 Final thoughts

This work aimed to create proposals that would reduce the lead time of the sugarcane CLT process in a factory of the sugarcane energy sector through tools used in QRM, specially MCT and detective QRM. The improvements suggested were based in needs pointed by the factory itself in technical visits to the harvest fields and according to analysis of the collected data. The goal of these proposals was, in first hand, to reduce the time spent by the harvester "waiting for transshipment" in 40%, once this would impact directly not only the efficiency of the harvester, but also the necessary volume in stock of the harvested sugarcane in the patio of the factory.

To obtain success in these proposals we used methods of QRM proposed by Suri (2010): to look at the working process under a different perspective of the current view of the company, also to focus in the reduction of the lead time; make clear to all in the company that the reason of the QRM is not merely to reduce time to demand for more work in a faster speed, but to reduce time to create a company with more success in the future; and, to train the company workers to change their thought.

Considering on the 40% reduction of the time spent by the harvester "waiting for transshipment" we observed a 6% increase in the efficiency of the harvester. This would provide a reduction of R$ 0.53 in each tone harvested resulting in a total save of R$ 1,172,784.00 per year, not yet considering the impact in other processes. The stock of sugarcane waiting to be milled, in its hand, would be reduced in 8.43%.

Based on the QRM principles, this study showed that through the proposals the possible improvements derived from these tools, strengthening the theory addressed by Suri in 1998, since it proved the versatility of QRM once it was applied in a process different from the context in which this tool is usually used.

The article contributed for the consolidation of QRM in a sector that represents approximately 2% of the Brazilian GDP. This would make valid the tools for analysis and improvement of the lead time in the country that is the biggest sugarcane producer in the world.

Due to the imposed State Law n.11.241/02, 2002 turning into mandatory the sugarcane harvest to be done without fire burnings, the harvesters are being more and more in every new harvest. Therefore, the study here performed, if put into practice, will bring significant economy to all the sugar chain production in São Paulo state.

Since the CLT process means 40% of all the production costs, one must take into notice the demands for reduction of the lead time, just as other processes that might be reorganized or rethought to lessen the waiting time. Another suggestion for future studies is to analyze how to deal with unpredicted weather obstacles, once the climatic conditions are responsible for a great portion of time and product loss in the CLT process.

All this further thoughts should motivate future studies to apply and validate the proposals brought in this work and also the application of a QRM training to put in the workers' mind the importance of observing the reduction of the lead time as a relevant indicator in the production process.

References

Borja, P., Costas, J., Puche, J., Pino, R., La Fuente, D. (2018). The value of lead time reduction and stabilization: a comparison between traditional and collaborative supply chains. *Transportation Research Part E, Logistics and Transportation Review*, 111, 165-185. http://dx.doi.org/10.1016/j.tre.2018.01.014.

Centro de Tecnologia Canavieira – CTC. (2014). Revista Censo CTC – Safra 2013/14 – Brasil. Piracicaba: CTC. Retrieved in 2016, June 07, from http://www.ctcanavieira.com.br/downloads/censo13-14.pdf

Companhia Nacional de Abastecimento – CONAB. (2016). Acompanhamento da Safra Brasileira de Cana-de-açúcar, safra- 2015/2016 – Brasil. Brasília: CONAB. Retrieved in 2016, July 29, from http://www.conab.gov.br/OlalaCMS/uploads/arquivos/16_04_14_09_06_31_boletim_cana_portugues_-_4o_lev_-_15-16.pdf

Dourado, T. H., Cassia, M. T., Compagnon, A. M., Silva, R. P., & Catasse, M. G. (2014). Colheita mecanizada de cana-de-açúcar monitorada por meio de computador de bordo. In *Anais do XLIII Congresso Brasileiro de Engenharia Agrícola-CONBEA* (p. 1-4). Jaboticabal: SBEA.

Ericksen, P. D., Stoflet, N. J., & Suri, R. (2007). *Manufacturing Critical-path Time (MCT): the QRM metric for lead time*. Wisconsin-Madison: Center for QRM.

Lazzarini, C. M. C., Santos, A. G., Saramago, S. F. P., & Faria, C. A. (2010). Modelo de otimização do transporte de cana-de-açúcar das frentes de corte para usinas. In *Anais do VI Congresso Nacional de Engenharia Mecânica*. Campina Grande: ABCM. Retrieved in 2018, May 02, from http://www.abcm.org.br/anais/conem/2010/PDF/CON10-0164.pdf

Lima, A. D., Bachega, S. J., Godinho Filho, M., Cruz, V. J. S., & Rossi, J. M (2013). Proposta de aplicação da abordagem Quick Response Manufacturing (QRM) para a redução do lead time em operações de escritório. *Produção*, 23(1), 1-19. http://dx.doi.org/10.1590/S0103-65132012005000028.

Meurer, A. P. S., & Lobo, D. (2015). Caracterização da logística do sistema agroindustrial (SAG) da cana-de-açúcar no centro-oeste do Brasil. *Revista Economia & Gestão*, 15(39), 45-65.

Narimoto, L. R. (2015). *A gênese das gêneses instrumentais: o projeto no uso de máquinas colhedoras de cana-de-açúcar no Brasil e na Austrália* (Tese de doutorado), Universidade Federal de São Carlos, São Carlos. 33 p.

Neves, M. F., & Trombin, V. G. (2014). *A dimensão do setor sucroenergético: mapeamento e quantificação da safra 2013/14*. Ribeirão Preto: Markestrat, Fundace.

Programa de Educação Continuada em Economia e Gestão de Empresas – PECEGE. (2012). *Custos de produção de cana-de-açúcar, açúcar e etanol no Brasil: acompanhamento da safra 2011/2012 - Centro-Sul.* Piracicaba: Universidade de São Paulo, Escola Superior de Agricultura "Luiz de Queiroz", Programa de Educação Continuada em Economia e Gestão de Empresas, Departamento de Economia, Administração e Sociologia. 57 p.

Rangel, J. J. A., Franciso, L. E. S., Azevedo, L. R., Cunha, A. P., & Vianna, D. S. (2009). Modelo de simulação para análise do lead time da cana-de-açúcar transportada para uma usina. In *Anais do XLI Simpósio Brasileiro de Pesquisa Operacional* (pp. 1214-1225). Porto Seguro: SOBRAPO. Retrieved in 2016, July 29, from http://www.din.uem.br/sbpo/sbpo2009/artigos/54371.pdf

Saes, E. V., & Godinho, M. Fo. (2011). Quick Response Manufacturing approach in a school supply company: proposal and analysis of expected results. *Gestão & Produção*, 18(3), 525-540. http://dx.doi.org/10.1590/S0104-530X2011000300007.

São Paulo. (2002, 20 de setembro) *Lei nº 11.241, de 19 de setembro de 2002. Dispõe sobre a eliminação gradativa da queima da palha da cana-de-açúcar e dá providências correlatas*. São Paulo: *Diário Oficial do Estado de São Paulo.* Acesso em: 06 jun. 2016 from http://www.al.sp.gov.br/repositorio/legislacao/lei/2002/lei-11241-19.09.2002.html

São Paulo. Secretaria do Meio-Ambiente. (2014). *Protocolo agroambiental do setor sucroenergético paulista: dados consolidados das safras 2007/08 a 2013/14*. São Paulo: SMA. Retrieved in 2016, June 06, from http://arquivos.ambiente.sp.gov.br.

Scheidl, H. A., & Simon, A. T. (2012). Avaliação do processo de terceirização do corte mecanizado, carregamento e transporte de cana-de-açúcar. *Revista de Ciencia y Tecnología*, 17(33), 103-118. http://dx.doi.org/10.15600/2238-1252/rct.v17n33p103-118.

Severino, M. R., Lage Junior, M., Campanini, L., Guimarães, A. A., Godinho Filho, M., & Aguilera, M (2010). Proposta de utilização do sistema Period Batch Control para redução de lead time em uma empresa de bens de capital. *Produção*, 20(4), 612-625. http://dx.doi.org/10.1590/S0103-65132010005000030.

Silva, A. F., Marins, F. A. S., Ribeiro, I. M., Lopes, P. R., & Montevechi, J. A. B. (2011). Planejamento otimizado para colheita de cana de açúcar de uma usina sucroalcooleira. In *Anais do XLIII Simpósio Brasileiro de Pesquisa Operacional* (pp. 1242-1254). Ubatuba: SBPO. Retrieved in 2016, June 06, from http://www.din.uem.br/sbpo/sbpo2011/pdf/87376.pdf

Solinftec. (2014) *Fila única de transbordos diminui tempos perdidos e equipamentos envolvidos no processo de colheita*. Retrieved in 2016, July 27, from: http://www.solinftec.com.

Suri, R. (1998). *Quick response manufacturing: a companywide approach to reducing lead times*. Portland: Productivity Press. http://dx.doi.org/10.4324/9781482278101.

Suri, R. (2010). *It's About Time – The competitive Advantage of Quick Response Manufacturing*. New York: Productivity Press.

Uzsoy, R. (2010). An exploratory analysis of two iterative linear programming: simulation approaches for production planning. *IEEE Transactions on Semiconductor Manufacturing*, 23(3), 422-445.

Wu, D., Kefan, X., Hua, L., Shi, Z., & Olson, D. L. (2010). Modeling technological innovation risks of an entrepreneurial team using system dynamics: an agent-based perspective. *Technological Forecasting and Social Change*, 77(6), 857-869. http://dx.doi.org/10.1016/j.techfore.2010.01.015.

Yin, R. K. (2015). *Estudo de Caso: planejamento e métodos* (C. M. Herrera, Trad., 5a ed.). Porto Alegre. The Bookman.

Zuquette, G., Bozutti, D. F., & Costa, M. A. B. (2015). Análise dos fatores críticos de sucesso na logística de abastecimento em empresas do setor alcooleiro. In *Anais do XXXV Encontro Nacional de Engenharia de Produção*. Fortaleza: ABEPRO. Retrieved in 2016, July 27 from http://www.abepro.org.br/biblioteca/TN_STP_206_222_27705.pdf

ANNEX 1. The following table (Board 1) brings the questions that were made through the "QRM detective" method to the moto-mechanization manager of the factory.

Board 1 – Questions used in the "QRM detective" strategy done to the moto-mechanization manager of the factory

QRM Detective question (1st phase)
What is the history of the idle juliets in the factory?
What is the maximum time the sugarcane can be laid in stock to be milled in the factory still in na adequate quality?
What is the average of loaded juliets that have been lost due to the long time of the cane laid in the patio?
What is the cost of a lost juliet?
In a case of two trucks meeting in a narrow road, impeaching them both to pass simultaneously, what is the correct proceeding to be taken? Is there a prevention procedure?
What is the average capacity (tons) of the juliet?
Which are the agricultural variables? Whats is the nature of these variables?
Which are the reasons of unavailability of a harvester?
Which ate the current forms of guaranteeing the constant arrival of cane in the factory?
How do all the basis work to grant the uninterrupted production of the factory?
Does the traffic control (truck dispatching) update its system (of dynamic allocation of the trucks) according to the information provided by the basis leaders via radio?
If the shift exchange in the basis would be alternated, wouldn't it be better for the stock stability in the patio of the factory? In other words, supposing that in the shift changes the stock in the patio decreases. If in every front there would be different times for the shifting, would the system be better? Or is this not possible?

Source: Elaborated by authors