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INVENTORY MANAGEMENT AT GRUPO NOBRE: THE METHANOL CHALLENGE

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ABSTRACT

This teaching case aimed to discuss the importance of inventory management techniques in defining the purchasing strategy, in the context of the industrial operations and production of biodiesel. From the perspective of Ricardo Mendes, purchasing director, the text proposes a discussion on the nuances involved in the purchasing strategy based on long-term contracts with reliable suppliers and on spot markets. The teaching case invites students to discuss and apply the concepts and calculations of cycle and safety stock to support decisions related to the purchasing strategy. It is a real narrative based on facts experienced by the authors that aims to provide students with a greater understanding of the fundamental differences between long-term suppliers and spot relationships, a central dilemma in purchasing management, and to provide inputs so that they can calculate the costs associated with inventory management arising from each purchasing strategy and reflect on the risks of each strategy. This case is recommended for Supply Chain Management courses, with Inventory Management and Purchasing Management modules, especially in MBA, specialization, or professional master's classes.

Keywords: Inventory Management, Purchasing Management, Cycle Stock, Safety Stock, Supply Chain Management.

GESTÃO DE ESTOQUES NO GRUPO NOBRE: O DESAFIO DO METANOL

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RESUMO

Este caso de ensino teve por objetivo discutir a importância das técnicas de gestão de estoques na definição da estratégia de compras em operações industriais, tendo como pano de fundo o metanol, um insumo vital para a produção de biodiesel. A partir da perspectiva de Ricardo Mendes, diretor de compras de uma empresa desse segmento, o texto propõe uma discussão sobre as nuances envolvidas na definição da estratégia de compras baseada em contratos de longo prazo firmados com fornecedores de confiança e na gestão de suprimentos baseada em mercados *spot*. O caso de ensino convida os alunos a discutirem e praticarem os conceitos abarcados pelas técnicas de estoque cíclico e estoque de segurança para embasar as decisões ligadas à estratégia de compras. Trata-se de uma narrativa baseada em fatos vivenciados pelos autores que tem por objetivo auxiliar os alunos na compreensão sobre as diferenças fundamentais entre fornecedores de longo prazo e relacionamentos *spot*, um dilema central na gestão de compras, e fornecer insumos para que eles possam calcular os custos associados com a gestão de estoques decorrentes de cada estratégia de compra. Este caso é recomendado para cursos de Gestão da Cadeia de Suprimentos, com módulos de Gestão de Estoques e Gestão de Compras, principalmente em turmas de MBA, especialização ou mestrado profissional.

Palavras-chave: Gestão de Estoques, Gestão de Compras, Estoque Cíclico, Estoque de Segurança, Gestão da Cadeia de Suprimentos.

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INTRODUCTION

At the end of a long workweek, Ricardo Mendes, the director of Nobre Group's purchasing department, sat in his office reflecting on the upcoming meeting with shareholders to decide the supply strategy for methanol, the most critical input in biodiesel production. With over 50 years of experience in the soy agro-industrial chain, the Nobre Group is a major player in the commodity trading sector. To add value to its production, the group invested in the construction of a biodiesel plant in 2015 within the company's industrial park in Araguari, Minas Gerais (MG).

Ricardo is responsible for negotiating, purchasing, and managing relationships with all suppliers providing inputs to the group's plants in the Araguari industrial park. He sharpened his professional skills in the commodity trading sector, and his extensive academic and professional experience in buying and selling has shaped him into a professional not averse to taking risks. He joined the Nobre Group in January 2015, but his journey within the company has been far from smooth.

As the business group has grown organically over its 50 years of existence, the shareholders' strategy has always been based on a conservative management model that prioritizes business sustainability to the detriment of growth associated with risk-taking. Thus, Ricardo's innovative style and frankness about the company's problems have often upset some people. Despite his role in implementing significant changes in the purchasing strategy for industrial items that resulted in substantial cost reductions in the products sold by the group, some of his ideas did not have good results and he found himself in "deep water".

At their last meeting, the group's president said to Ricardo: "*You keep saying that our methanol purchasing strategy is flawed, and we're going to be able to review it soon, when our long-term contract with the current supplier ends. You need to show us a good result with what you're suggesting.*" Ricardo knew his job was at stake and he needed to define a winning strategy for methanol. "*These long-term contracts with traditional suppliers guarantee high responsiveness,*" he thought. "*On the other hand, purchasing on the spot market can be cheaper for us.*" Leaning back in his chair, he began to contemplate how to navigate this difficult decision.

1. BIODIESEL PRODUCTION IN THE NOBRE GROUP AND THE IMPORTANCE OF METHANOL

Biodiesel was introduced into Brazil's energy matrix by Law No. 11,097 of January 13, 2005. Seventeen years after it started, the Brazilian biodiesel market is now fully established. In 2021, the biodiesel sector produced nearly 7 billion cubic meters of this product, valued at over R$40 billion. This thriving industry holds significant socioeconomic importance for the country, with all diesel sold at gas stations in Brazil currently containing 10% biodiesel.

Driven by the growth of the biodiesel industry, several companies, such as ADM, Bunge, Cargill, Cofco, and JBS, which were already operating in the industrial transformation segment of agro-industrial chains, decided to invest in biodiesel production plants. The Nobre Group, already a producer of soybean oil, also saw value in investing in a biodiesel production unit using this oil to enhance the company's operations.

The inauguration of the biodiesel refinery in the Araguari industrial park in 2017 consolidated the company's industrial operations for processing and crushing soybeans and producing biodiesel. Appendix 1 shows a flowchart of the entire industrial operation. Biodiesel is produced through a chemical process involving the reaction of triglycerides, a fatty material of animal or vegetable origin, with alcohol, resulting in biodiesel (product) and glycerin (by-product). The Nobre Group uses soybean oil as the fatty material and methanol as an extracting alcohol.

Soybean oil and methanol are the largest contributors to the production cost of biodiesel, accounting for 85% of the overall manufacturing expenses. The stoichiometry of the transesterification process at the Nobre Group can be summarized as follows: every 1,000 kg of soybean oil entering the industrial process requires 100 kg of alcohol for the reaction to occur. This process typically produces 985 kg of biodiesel and 95 kg of glycerin, on average.

The Nobre Group plant has a monthly production capacity of 36,000 tons of biodiesel. The industrial park contains three tanks exclusively used for storing biodiesel, each with a maximum capacity of 2,000 tons. There are also three more tanks of 3,000 tons each for storing soybean oil and a 1,200-ton tank for methanol. Due to technical limitations, all tanks maintain a 5% "tank head." Appendix 2 illustrates the Nobre Group's biodiesel production flow.

The static storage capacities for different products are managed differently. The tank structure used exclusively for soybean oil typically operates near its maximum capacity, while the static capacity available for biodiesel storage is managed at an average level of 3,000 tons. Precise management of this stock is crucial, as space must be maintained in the tank to absorb any excess production if buyers fail to take delivery of the biodiesel they have purchased. The methanol tank, on the other hand, is operated to maintain the smallest possible volume of product in stock.

2. THE METHANOL SUPPLY CHAIN IN BRAZIL

One of the biggest challenges in biodiesel production is managing methanol purchases and inventory. Domestic demand for methanol is highly dependent on imports. In 2017 and 2018, for example, Brazil consumed 1,158,000 and 1,206,000 tons of methanol, respectively, with the entire demand met by international suppliers. Globally, major producers of this alcohol include Venezuela, Trinidad and Tobago, Chile, and Middle Eastern countries. Appendix 3 provides data on annual methanol consumption in Brazil between 2008 and 2018, indicating the amount produced locally and imported.

The Brazilian methanol market is primarily served by two types of suppliers: producers and trading companies. The former have strategically located plants worldwide and maintain adequate logistics infrastructure in major consumer markets, including Brazil, to handle port reception, unloading, and overland transportation to consumers. They offer customers a high level of service and highly predictable lead times.

In contrast, trading companies operate by capitalizing on opportunities to purchase methanol from smaller producers that lack direct access to consumer markets, then reselling it to customers with immediate demand or those seeking more competitive prices. These suppliers have no loading or unloading infrastructure in consumer countries, relying instead on short-term leases or position exchanges with other trading companies. Unlike production companies, trading companies offer a lower level of service, and agreed delivery times tend to vary greatly. Purchasing from this type of supplier is commonly referred to as spot buying.

3. NOBRE GROUP'S CURRENT STRATEGY FOR MANAGING ITS METHANOL PURCHASES AND INVENTORY

Domestic demand for methanol is directly linked to the Nobre Group's performance in biodiesel sales. Given the strategic position of its biodiesel plant, the company sells large volumes of biodiesel every month. On average, the biodiesel business unit operates close to 80% of its daily production capacity, with average daily demand for biodiesel being distributed normally. Appendix 4 includes records of daily biodiesel production between May and August 2021.

Since the beginning of its biodiesel operation, the Nobre Group has purchased methanol from large production companies through long-term contracts lasting 18 months. These suppliers hold considerable bargaining power with biodiesel producers, which is reflected is an exclusivity clause in the contract, effective for the period of the supply agreement. Once a purchase and sale agreement is finalized with these suppliers, the biodiesel producer is contractually prohibited from purchasing methanol on the spot market.

The main advantage of this supply strategy is its reliability and accuracy. The average lead time is two days, with lead time variability expressed by a standard deviation of one day. Considering the tank's usable capacity, the Nobre Group's purchasing team requests new lots of methanol when the stock reaches four days of consumption. A batch of methanol is consumed in seven days, and the supplier guarantees to replenish it at this same frequency.

When methanol unit prices are analyzed on a monthly basis, they show variation. This is because methanol prices are based on CIF[1] conditions, taking into account the international market price (selling price FOB[2] Gulf of Mexico), the exchange rate, sea freight logistics costs to the port of Santos, and overland logistics costs to Araguari. Appendix V contains records of the average monthly prices of methanol purchased by the Nobre Group from its exclusive supplier in

1 Cost, Insurance, and Freight: CIF is an incoterm used in foreign trade to indicate that freight and insurance costs are included in the sale or offer price, showing that the seller bears the cost of such items. Purchase and sale transactions in the domestic market have incorporated this term to refer to the sales price including the cost of shipping to the destination.

2 Free on Board: FOB is an incoterm used in foreign trade to indicate that shipping and insurance costs are not included in the sale or offer price, showing that the buyer must bear the cost of such items. Purchase and sale transactions in the domestic market have incorporated this term to refer to the sales price that does not include the cost of shipping to the destination.

Reais (BRL) per ton over the last 30 months (prices in R$/ton, CIF Araguari — exclusive supplier).

The Nobre Group incurs specific costs associated with purchasing and receiving methanol. The company outsources the service of checking the quality, volume, and safety of the methanol-loaded trucks arriving at its facility; this service is charged at R$2,000 per visit. The Nobre Group also incurs expenses related to renewing its supply contract. Before signing a new agreement, the group hires a law firm that specializes in international negotiations to assist the company in the legal discussions, primarily to clarify the risks associated with the agreement. The cost of hiring this law firm for the service is R$95,000.

4. BUYING METHANOL ON THE SPOT MARKET

The alternative to purchasing methanol through long-term contracts is to negotiate prices on the spot market. This shift, however, requires assessing the potential reduction in methanol purchasing operations against the risks associated with such a strategy. Anticipating the need for this analysis, Ricardo systematically gathered the necessary information over time to calculate the Araguari price CIF when purchased on the spot market. He did this by collecting data on average monthly sales prices of methanol FOB Santos from March 2019, the monthly average exchange rate, and the monthly average freight prices from Santos to Araguari (Appendix 5).

Assessing the potential for supply chain disruptions in the event of adverse conditions affecting methanol supply is also essential. This is a crucial issue since a lack of methanol would halt biodiesel production. The sales contracts for this product allow the producer to fail to deliver up to 5% of the total monthly volume sold, with fines for non-compliance ranging from 80 to 100% of the total value of the shortfall.

To assist in his analyses, Ricardo consulted with his peers from other biodiesel-producing companies who confirmed what he already knew from his own professional experience: methanol trading companies are highly inconsistent in terms of delivery volumes and lead times. One colleague provided him with the delivery lead time history of a large trading company operating in the spot market. (Appendix 6).

If a purchasing management strategy based on the spot market is chosen, it is crucial to define the methanol safety stock volumes that must be kept at the manufacturing unit. The greater the volumes stored in the form of safety stock, the lower the risk of supply chain disruption due to product unavailability. On the other hand, the costs involved with holding methanol stocks must also be considered.

One of the most relevant items associated with the Nobre Group's stocking inventories is the weighted average cost of capital. The group's financial area estimated a capital cost figure of 15.5% p.a. for 2022 and 2023. In addition, due to the product's highly flammable nature, there are other expenses related to operational safety. The methanol tank is equipped with a pressure and heat monitoring system, which the group outsources at a cost of R$100 per ton of stored product per month. The fixed costs associated with the industrial park's inventory are also apportioned among the various items the group stores, resulting in a total expense of R$ 150 per ton of product stored per month.

5. REVISITING THE STRATEGY FOR MANAGING PURCHASES AND INVENTORY

Following his meeting with the CEO and with the contract renewal period with the company's exclusive supplier approaching, Ricardo began to consider whether to maintain the existing strategy or change it. In the past, he had opted to maintain the purchasing strategy based on long-term contracts due to a lack of sufficient data regarding demand, lead times, spot market prices, and other factors. *"Any decision to change the methanol supply strategy at that time would've been a shot in the dark,"* he thought. Now, however, he had the necessary data and experience to analyze the matter and make a well-informed decision.

He now needed to leverage his experience and analytical skills to determine the best strategy for managing Nobre Group's methanol purchases and inventory. Based on the data he had collected, he could weigh the pros and cons of managing methanol procurement and storage either via long-term contracts or via the spot market. Ricardo called in the department's top analyst and said: *"I need your help to put together these analyses and a presentation for the group's shareholders."*

6. TEACHING NOTES

6.1. Teaching objectives

This teaching case narrates the story of a purchasing director who evaluates the group's supply strategy for methanol, a critical ingredient in biodiesel production. The director's analysis invites students to reflect on purchasing and inventory management using theories such as Economies of Scale Management in a Supply Chain (Cycle Inventory), Uncertainty Management in a Supply Chain (Safety Stock), and Determining the Optimal Level of Product Availability. The teaching case emphasizes the importance of quantitative data in the decision-making process within these fields. This is a fictional narrative based on the authors' own professional experiences during their careers in companies (an armchair case). The case was designed to promote an understanding of key aspects of inventory and purchasing management, enhancing the analytical and quantitative reasoning skills of students and their ability to work with unstructured data. After studying this case, students are expected to:

- measure the costs of the purchasing strategy employed, from the perspective of the Cycle Inventory Theory;

- estimate the service level provided by the adopted purchasing strategy, from the perspective of the Safety Stock Theory.

To achieve these objectives, the case provides information about the two types of suppliers in "The methanol supply chain in Brazil" section. The following section, "Current methanol purchasing and inventory management strategy in the Nobre Group," outlines how the company has always managed the supply of methanol. This is followed by information about purchasing on the spot market. These last two sections provide important quantitative data to support calculations and discussions on purchasing and inventory management strategies for this input. In addition, the case also provides details about the biodiesel industrial operation, which will be relevant in quantitative discussions of the case. To encourage students to weigh the pros and cons of possible purchasing and inventory management strategies, the case concludes with the dilemma faced by Ricardo.

This case is suitable for use in courses on Supply Chain Management, Inventory Management, and Purchasing Management. It is recommended for MBA, specialization, or professional master's degree classes, as well as undergraduate classes in Business Administration or Production Engineering. Given the complexity of the case, instructors may need to dedicate time and effort to explain industrial operations, which could extend the time required to teach them. We suggest that this case be applied after the theoretical content of inventory management has been presented so that students are familiar with the mathematical tools necessary for the exercise.

6.2. Theoretical links

One of the main challenges in supply chain operations is managing the impact of purchasing strategies on global inventory costs, namely order costs, inventory holding costs, and product costs. Purchasing large product lots can lead to discounts per product unit and lower order costs. On the other hand, this strategy tends to increase inventory holding costs. Purchasing strategies based on acquiring smaller lots minimize inventory holding costs but maximize order and, possibly, product costs. The Economic Order Quantity (EOQ) is the amount of product that must be purchased to optimize the costs of ordering and holding inventory.

Equally important is managing operations to ensure that the purchasing strategy, combined with effective inventory management, achieves the desired level of product availability for the operation. Measuring the level of product availability in an operation employs two metrics: service level and fill rate. Operations with high levels of availability are achieved through a well-balanced safety stock and by managing the uncertainties inherent in the operation, such as variability in demand and lead time.

The theory of Economies of Scale Management in a Supply Chain (Cycle Inventory) covers the dynamics of inventory, order and product holding costs depending on the purchasing strategy adopted. It aids in decision-making regarding the most cost-effective purchasing and inventory management approach. The theories of Uncertainty Management in a Supply Chain (Safety Stock) and Determining the Ideal Level of Product Availability help managers in mitigating the risks of stock shortages due to purchasing strategies and the size of safety stock levels. This case study allows students to apply these theories to define the optimal purchasing and inventory management strategy for the Nobre Group.

The essential literature indicated for both the teacher and students is Chopra and Meindl (2016), who discuss the key theories in supply chain management and includes numerous practical exercises. This teaching case is inspired by the model suggested by Chopra and Meindl (2016), delving deeper into the theories of Managing Economies of Scale in a Supply Chain (Cycle Inventory), Managing Uncertainties in a Supply Chain (Safety Stock), and Determining the Ideal Level of Product Availability. Specifically, it is suggested that both teacher and students read Chapters 11 (Management of Economies of Scale in a supply chain: Cycle Inventory); 12 (Uncertainty Management in a Supply Chain: Safety Stock); and 13 (Determining the Ideal Level of Product Availability). Additionally, Hammond (2018) can be used as a complementary resource. This material offers richer conceptual details than Chopra and Meindl (2016), providing fewer quantitative examples. This is, therefore, an excellent material to complement that by Chopra and Meindl (2016).

7. CASE DISCUSSION / ANALYSIS

Methanol is an important input across various industrial sectors. Since it is not produced in Brazil, companies must develop and implement supply strategies to minimize the risk of shortages.

A supply strategy based on long-term supply contracts consists in negotiating monthly purchase volumes with a major international supplier. Such suppliers are able to guarantee a high level of service and accurate lead times due to their comprehensive logistics infrastructure at all stages of the supply chain. In return, they require buyers to commit to long-term supply contracts (between 12 and 18 months), often with an exclusivity clause. Prices charged in these contracts are also generally higher than those found in the spot market.

A supply strategy based on the spot market comprises purchasing methanol according to the company's needs. In this case, there is no prior agreement with any supplier, and negotiations take place regularly in the market. The prices charged and payment and delivery conditions are freely agreed upon during each negotiation. The main players in this market are trading companies, which actively seek opportunities to buy and sell methanol globally on a daily basis. Large methanol-producing companies typically do not participate in this market.

As trading companies lack production facilities or logistics infrastructure, they provide a lower level of service and lead times vary considerably. On the positive side, trading companies tend to sell methanol at lower prices than those charged by large suppliers via long-term contracts, due to their ability to source from various suppliers and avoid high logistical costs. This also means that they are unstable and often unreliable suppliers.

This teaching case invites reflection on the dilemma of safe purchasing through long-term contracts, or supply via the spot market, which is subject to greater risks. To facilitate this discussion, the case provides quantitative data, enabling analysis of possible purchasing and inventory management strategies based on traditional supply chain management parameters taken from literature: lot size purchased, inventory replenishment point, degree of uncertainty in demand and supply, cycle service level, fill rate, total stock cost (order cost, stock holding cost, and cost of materials), and others.

8. SUGGESTED TEACHING PLAN

The way in which the case is applied must consider the maturity of the class. With undergraduate students, more time should be allocated to providing a detailed contextualization of the operational process and industrial yields. With specialization and professional master's students who focused on supply chains or operations, less time can be made available to discuss this case, as the introductory part on the operational process does not require as much detail. In all instances, students must have read the material in advance.

Given the complexity of the case, which requires a certain degree of understanding for data interpretation calculation, it is recommend that the case be applied in various steps throughout the course. Table 1 suggests some activities that can be used by teachers.

9. QUESTIONS FOR DISCUSSION

The following questions seek to assist teachers prepare an Excel spreadsheet that will serve as an analytical tool for decision-making regarding the best strategy for managing purchases and inventory. To provide a systematic approach, the questions are divided into four groups: general questions, current strategy (purchasing via contract), strategy evaluated (purchasing on the spot market), and a strategy based on EOQ. A suggested spreadsheet containing all the necessary calculations for the case accompanies these teaching notes.

9.1. Group 1: General questions

1) What types of uncertainty did Ricardo Mendes face when managing methanol purchases and stocks, and what are their implications?

Operations for managing methanol purchases and stocks are subject to supply and demand uncertainties. Supply uncertainty arises from the variability in demand (methanol consumption): daily consumption of this input varies according to the daily production of biodiesel. Average methanol consumption and the respective standard deviation can be inferred from the daily biodiesel production data presented in Appendix 4.

Supply uncertainty comes from the way the lead time behaves. In the case of the strategy based on a long-term contract (Section 3), the case shows average lead times and their respective standard deviation. For the alternative strategy, these two parameters can be calculated using the data provided in Appendix 4.

In an ideal scenario with no uncertainty, methanol demand and lead time would be fixed, *i.e.*, eliminating variability. In such a context, Ricardo could manage operations without any safety stock, since the lead time promised by the supplier would be perfectly met and methanol demand would be predictable. Howe-

Table 1. A guide for applying the case study in the classroom.

Step		Description	Tool
1	Introduction	The objective of this step is to describe in general terms the problem presented in the case. At this point, it is suggested that teachers should start a discussion about the uncertainties that affect the operation and their influence on decision-making processes regarding purchases and inventory. There is an opportunity at this point to present the concepts of cycle inventory, safety stock, and product availability levels in a didactic manner. The questions in Group 1, presented below, help promote this discussion.	Whiteboard
2	Analysis of the current scenario	In the current scenario the company purchases the methanol it needs via a long-term contract. The objective of this step is to evaluate the level of availability offered by the current strategy by calculating the cycle service level (CSL) and the service rate (fr). Based on the assumptions arising from the case and on intermediate calculations (presented in the "Questions for discussion" section of the teaching notes and shown in the spreadsheet attached to this case), the total inventory cost (TC) should be calculated. Once the calculations have been made, there should be a discussion based on CSL, fr, and TC. The questions in Group 2, presented below, assist in this discussion.	Whiteboard and MS Excel
3	Analysis of the alternative scenario	In the alternative scenario, the company would acquire the methanol it needs from the spot market. The objective of this step is to assess the level of availability offered by this strategy by calculating the CSL and the fr and TC associated with it. We suggest that a discussion should then follow on the pros and cons of each strategy. The questions in Group 3, presented below, can help guide this discussion.	Whiteboard and MS Excel
4	Analysis of the current scenario using economic order quantity (EOQ)	Considering the premises of the long-term contract-based purchasing strategy, we suggest calculating the ideal lot size for stock replenishment that would deliver the best possible total cost. To do so, it is important to consider the minimum fulfillment rate of 95%. At the end of these calculations, the advantages and disadvantages of each strategy can be discussed. Question 4 can help in this discussion.	Whiteboard and MS Excel

ver, this ideal scenario is rarely achievable. The reality of operations resembles the context experienced by Ricardo: deliveries from suppliers and demand for the product are variable. The literature on Supply Chain Management discusses how to deal with the uncertainties that affect operations: Managing Uncertainties in a Supply Chain (Safety Stock).

One of the most recommended management tools for preventing stock shortages due to variability in demand or lead time is the formation and management of safety stocks. Safety stocks are determined by the degree of operational uncertainty and the desired level of product availability. The greater the degree of uncertainty of an operation and the greater the level of availability desired, the larger the required volume of safety stock. The reverse is also true. Supply Chain Management literature discusses how to measure the level of availability in different uncertainty contexts and the size of the safety stock required: Determining the Ideal Level of Product Availability.

2) Considering the history of daily biodiesel production (Appendix 4) and the specific consumption of methanol (spec_cons), average demand (R) and the standard deviation (σR) associated with consumption can be calculated, discussing how σR influences the decision regarding safety stock and product availability level.

Producing 985 kg of biodiesel consumes 100 kg of methanol, thus (Equation 1):

$$\boldsymbol{spec\_cons} = 100kg \div 985kg \tag{1}$$
$$\boldsymbol{spec\_cons} = 10.15\%$$

If the specific methanol consumption is known, the historical series of biodiesel production shown in Appendix 4 can be used to calculate daily methanol consumption for the period in question. To do so, each observation of the daily biodiesel production is multiplied by the specific consumption calculated above, resulting in a new column showing the daily methanol consumption in the operation. Based on this new series of data, the average and standard deviation can be calculated (Equations 2 and 3):

$$\boldsymbol{R} = MEAN(num1;\ [num2];\ \ldots) = 97.37\ ton/day \tag{2}$$
$$\boldsymbol{\sigma_R} = STAND.DEV.A(num1;\ [num2]\ \ldots) = 0.87 \tag{3}$$

where *num1; [num2]...* represent the daily observed consumption of methanol.

Standard deviation in demand (σR) reflects the uncertainty in operational demand. The closer to zero, the lower the degree of uncertainty of the operation; the higher it is, the greater the uncertainty. The director must decide the appropriate safety stock size to ensure a certain degree of product availability. In a hypothetical scenario where holding costs are nonexistent, it would be logical to increase the safety stock as much as possible, thus mitigating the chances of product shortage. In reality, however, increasing the safety stock increases the costs of holding stocks, thereby increasing overall operational costs.

9.2. Group 2: Current strategy (purchasing via a contract)

3) In the current scenario, what are the reorder points (ROP), safety stock (SS) points, and the size of the shipment lot associated with it? Discuss the role of ROP in forming safety stocks and their impact on operation availability and total inventory costs.

Based on the calculation shown in Question 2, a new order is placed when four days of inventory (DI) are reached and given the useful volume of the tank, the ROP of this operation is 389.46 tons (Equation 4).

$$\boldsymbol{ROP} = R \times DI \tag{4}$$
$$\boldsymbol{ROP} = 97.37\frac{ton}{day} \times 4\ days$$
$$\boldsymbol{ROP} = 389.46\ ton\ of\ MeOH$$

The safety stock is then calculated (Equation 5):

$$\boldsymbol{ROP} = SS + R_L \tag{5}$$

Average demand during the lead time (R_L) is obtained by multiplying the average daily methanol consumption (calculated in the previous equation) by the lead time (L) (provided in Section 5 of the case). Thus (Equation 6):

$$\boldsymbol{SS} = ROP - RL \tag{6}$$
$$\boldsymbol{SS} = ROP - (R\ \times L)$$

$$SS = 389.46\ ton - \left(97.37 \frac{ton}{day} \times 2\ days\right)$$

$$SS = 194.72\ ton$$

Since the average daily methanol consumption (R, calculated previously) and the stock replenishment frequency (RF), shown in Section 4 as "time to consume methanol") are known, the lot size (Q) of the shipment from the supplier to the industry can be calculated (Equation 7).

$$Q = RF \times R \tag{7}$$

$$Q = 7\ days \times 97.37 \frac{ton}{day} = 681.56\ ton$$

The ROP figure comes from the theories of Uncertainty Management in a Supply Chain (Safety Stock) and Determination of the Ideal Level of Product Availability. It is the physical point of the stock at which the manager decides to place a new purchase order. The higher the stock level at the time of reordering, the greater — theoretically — the safety stock of the operation. The reverse is also true. Thus, ROP have implications in terms of the size of the safety stock of an operation and, consequently, on the level of availability offered by the operation.

The lot size (Q) plays a relevant role in determining total inventory cost. Purchasing managers who prioritize purchasing large lots are, from a theoretical point of view, prioritizing a reduction in the overall order costs and possibly a reduction in the total product costs (when suppliers offer a discount on the unit price for larger lots) over holding larger inventories with their associated costs. On the other hand, small lot purchasing strategies prioritize reducing holding costs but may incur in higher order and, possibly, product costs. The impact of lot size on total inventory cost is discussed in Managing Economies of scale in a Supply Chain (Cycle Inventory).

4) What are the cycle service level (CSL), fill rate (fr), and expected shortage per cycle (ESC) in the current scenario? Comment on how these measures help define purchase and inventory management strategies and discuss how are they theoretically related to safety stocks and operation uncertainty.

CSL indicates the probability of avoiding product shortages given specific ROP, R_L, and combined demand and supply uncertainties (σ_L) (Equation 8, 9 and 10):

$$R_L = R \times L = 97.37 \frac{ton}{day} \times 2\ days = 194.73\ ton \tag{8}$$

$$\sigma_L = \sqrt{(L \times \sigma_R^2) + (R^2 \times S_L^2)} = \sqrt{(2 \times 0.87^2) + (97.37^2 \times 1^2)} = 97.37 \tag{9}$$

$$CSL = NORM.DIST.N(x; mean; stand\_dev; 1) = NORM.DIST.N(ROP; R_L; \sigma_L; 1)$$

$$CSL = NORM.DIST.N(389.46; 194.73; 97.37; 1) = 99.86\% \tag{10}$$

The fill rate (fr) indicates the average waiting time to fulfill demand in each stock cycle, given a purchase lot size and ESC. Thus (Equations 11 and 12):

$$ESC = -SS \times \left\{1 - NORM.DISTP.N\left(\frac{SS}{\sigma_L}; 1\right)\right\} + \sigma_L \times NORM.DISTP.N\left(\frac{SS}{\sigma_L}; 0\right)$$

$$ESC = -194.72 \times \left\{1 - NORM.DISTP.N\left(\frac{194.72}{97.37}; 1\right)\right\} + 97.37 \times NORM.DISTP.N\left(\frac{194.72}{97.39}; 0\right) = 0.83\ ton \tag{11}$$

$$fr = 1 - \left(\frac{ESC}{Q}\right) = 1 - \left(\frac{0.83}{681.56}\right) = 99.88\% \tag{12}$$

CSL and fr are important product availability measures. They indicate the degree of responsiveness based on safety stock and uncertainties. ESC plays a fundamental role in determining fr; the greater the ESC, the lower the service rate offered to the customer tends to be.

CSL, fr, and ESC collectively represent the level of product availability offered by a given purchasing and inventory management strategy. In high-uncertainty contexts, higher product availability can be achieved by increasing safety stocks. Alternatively, uncertainties can be reduced. For example, logistics strategies aimed at reducing any variability in lead times can be discussed with the supplier. Likewise, there can be an investment in technology and/or collaboration with downstream supply chain partners with the aim of improving the quality of the information relating to demand behavior, thereby mitigating the bullwhip effect that increase the variability in demand perceived by the agents of the supply chain in an operation.

5) Calculate the total cost of inventory associated with the current purchasing strategy.

The total inventory cost (TC) consists of order costs (*order_cost*), inventory holding costs (*invent_hold_cost*), and material or product costs (*mat_cost*). To calculate TC, the components of the three costs must first be identified.

Order_cost is made up of the quality checking costs (*qual_cost_yr*) and the costs for drafting and evaluating the contract (*contr_cost_yr*). To calculate *qual_cost_yr*, both the cost of performing a quality check (R$ 2,000 *qual_cost,* information available in Section 4) and the number of orders placed over the course of a year must be considered. *Contr_cost_yr* is determined by considering the total cost for preparing a contract (R$ 95,000, *contr_cost,* information available in Section 4), applying the rule of three to calculate the annual cost of this item. To estimate the quality checking cost, the number of orders placed throughout the year (*orders_yr*) must be calculated (Equation 13):

$$\boldsymbol{order\_yr} = \frac{R_{annual}}{Q} \tag{13}$$

$$\boldsymbol{order\_yr} = \frac{97.37\,\frac{ton}{day} \times 365\ days}{681.56\ ton} = 52.14\ orders\ per\ year$$

where:

R_{annual}: annual demand for methanol (obtained by multiplying average daily demand by 365 days).

Thus (Equation 14):

$$\boldsymbol{qual\_cost\_yr} = order\_yr\ \times qual\_cost \tag{14}$$

$$\boldsymbol{qual\_cost\_yr} = 52.14\ orders \times \frac{R\$2{,}000.00}{order}$$

$$\boldsymbol{qual\_cost\_yr} = R\$104{,}285.71\ per\ year$$

To estimate the cost of preparing and evaluating the contract, the duration of the supply contract must be considered, which in this case is 18 months (as detailed in Section 4). Therefore (Equation 15):

$$\boldsymbol{contr\_cost\_yr} = \frac{contr\_cost}{18\ months} \times 12\ months \tag{15}$$

and (Equation 16):

$$\boldsymbol{order\_cost} = qual\_cost\_yr + contr\_cost\_y \tag{16}$$

$$\boldsymbol{order\_cost} = R\$104{,}285.71 + R\$63{,}333.33 = R\$167{,}619.05\ per\ year$$

Cust_man_est comprises two financial costs (*fin_cost_yr*): monitoring costs using an outsourced system (*monit_cost_yr*) and fixed cost apportionment (*fc_app_yr*). The three cost items are presented in Section 5.

To calculate the three expenses that make up *cust_man_est*, the average stock of this operation needs to be calculated. The mean useful stock (EM_U) is the sum of the cycle stock (EC) and SS (Equations 17 and 18).

$$\boldsymbol{CE} = \frac{Q}{2} = \frac{681.56\ ton}{2} = 340.78\ ton \tag{17}$$

$$\boldsymbol{MS_U} = CE + SS = 340.78\ ton + 194.72\ ton = 535.50\ ton \tag{18}$$

It is important to consider that, for operational reasons, it is not possible to extract the entire static capacity of the methanol storage tank (*cap_meth_st,* 1,200 tons); 5% of the volume is always reserved (*perc_tb*) as the "tank bottom" (TB). This information is presented in Section 2. Thus (Equation 19):

$$\boldsymbol{TB} = cap\_meth\_st\ \times perc\_tb \tag{19}$$

$$\boldsymbol{TB} = 1{,}200\ ton \times 5\% = 60\ ton$$

Since TB remains in the tank permanently, its existence must be considered alongside MS_U for *cust_man_est* purposes, resulting in the total average stock (MS_T) (Equation 20).

$$\boldsymbol{MS_T} = MS_U + TB \tag{20}$$

$$\boldsymbol{MS_T} = 535.50\ ton + 60\ ton \cong 595.50\ ton$$

To calculate *fin_cost_yr*, the cost of keeping one ton of methanol in stock for one year must be calculated. First, the average price of methanol in R$/ton must be calculated. This can be done using the average historical purchase prices of methanol "CIF Araguari — exclusive supplier" (C) as shown in Appendix V. Based on the unit price of methanol and the company's cost of capital (CC), *fin_cost_unit* can be calculated, and so, therefore, *fin_cost_yr* (Equations 21 and 22):

$$\boldsymbol{fin\_cost\_unit} = C \times CC \tag{21}$$

$$\boldsymbol{fin\_cost\_unit} = R\$4{,}255.83 \times 15.5\%\ p.a. = R\$659.65\ per\ ton\ per\ year$$

$$\boldsymbol{fin\_cost\_yr} = MS_T \times fin\_cost\_unit \tag{22}$$

$$\boldsymbol{fin\_cost\_yr} = 595.50\ ton \times R\$659.65\,\frac{ton}{year} \cong R\$392{,}833.30\ per\ year$$

Monit_cost_yr is a function of MS_T and the stock monitoring cost (*monit_cost,* Section 5). Therefore (Equations 23 and 24):

$$\boldsymbol{monit\_cost} = R\$100.00\ per\ ton\ per\ month \tag{23}$$

$$\boldsymbol{monit\_cost} = R\$100.00 \times 12 = R\$1{,}200.00\ per\ ton\ per\ year$$

$$monit\_cost\_yr = MS_T + monit\_cost \quad (24)$$

$$monit\_cost\_yr = 595.50\ ton \times \frac{R\$1{,}200.00}{year} \cong R\$714{,}616.81$$

Fc_app_yr is a function of MS_T and the apportioned fixed cost (*fc_app*, Section 6) (Equations 25 and 26).

$$fc\_app = R\$150.00\ per\ ton\ per\ month \quad (25)$$

$$fc\_app = R\$150.00 \times 12 = R\$1{,}800.00\ per\ year$$

$$fc\_app\_yr = MS_T \times fc\_app \quad (26)$$

$$fc\_app\_yr = 595.50\ ton \times R\$1{,}800.00 \frac{ton}{year} \cong R\$1{,}071{,}925.22$$

Therefore (Equation 27):

$$invent\_hold\_cost = fin\_cost\_yr + mon \quad (27)$$

$$invent\_hold\_cost = R\$392{,}833.30 + R\$714{,}616.81 + R\$1{,}071{,}925.22$$

$$invent\_hold\_cost \cong R\$2{,}179{,}375.22$$

The third cost, TC, is *mat_cost.* It is calculated by multiplying annual demand for methanol by its unit price. Thus (Equation 28):

$$mat\_cost = R \times C \quad (28)$$

$$mat\_cost = 97.37 \frac{ton}{day} \times 365\ days \times \frac{R\$4{,}255.83}{ton}$$

$$mat\_cost \cong R\$151{,}246{,}601.47$$

So (Equation 29):

$$TC = order\_cost + invent\_hold\_cost + mat\_cost \quad (29)$$

$$TC = R\$167{,}619.05 + R\$2{,}179{,}375.22 + R\$151{,}246{,}601.47 = R\$153{,}593{,}595.85$$

9.3 Group 3: Strategy evaluated (purchase on the spot market)

6) Considering the historical L of the operation for supplying methanol by purchasing it on the spot market (Appendix 6), calculate the average lead time of the methanol supply operation and its respective standard deviation (S_L).

Appendix 6 provides the historical record of the dates when new remittances of methanol were requested from the supplier and the dates these orders arrived at a competitor's biodiesel plant. The number of days it takes the supplier to fulfill the order (L) is determined by subtracting the delivery date from the respective order date (Equation 30):

$$L_i = DAYS(end\_date; start\_date) \quad (30)$$

L_i is the lead time for each observation.

The average lead time of the operation is calculated, along with the standard deviation of the lead time (S_L) associated with this historical series (Equations 31 and 32):

$$L = MEAN(num1;\ [num2];\ \dots) = 6.00\ days \quad (31)$$

$$S_L = STAND.DEV.A(num1;\ [num2]\ \dots) = 2.00 \quad (32)$$

where *num1; [num2]...* are each lead time observed and recorded in the historical series.

7) Calculate demand during the lead time and the combined standard deviation during the lead time.

As seen previously (Equations 33 and 34):

$$R_L = R \times L = 97.37 \frac{ton}{day} \times 6.00\ days = 584.22\ ton \quad (33)$$

$$\sigma_L = \sqrt{(L \times \sigma_R^2) + (R^2 \times S_L^2)} = \sqrt{(6 \times 0.87^2) + (97.37^2 \times 2^2)} = 194.74 \quad (34)$$

Comparing the standard deviation found in the analysis of purchases via the spot market with that of the purchase strategy using long-term contracts, it is evident that the combined uncertainties of demand and supply in that strategy (σ_L= 97.37) are mathematically more than twice those seen in this purchase model (σ_L= 194.74).

8) Based on the information and interpretation of the case, how can the average replenishment stock lot size be estimated in the context of purchasing on the spot market?

Unlike the model based on a long-term contract, where suppliers are able to guarantee a well-defined replenishment rate (replenishment frequency every seven days), in the spot market model, replenishment occurs based on the company's purchasing capacity and the availability of products from suppliers.

Given this context, and for calculation purposes, the replenishment frequency is established as coinciding with the average lead time required for delivering the loads. In these terms, a 584.20-ton lot of methanol (Q) is consumed every six days (L), on average. At the end of six days, a lot of 584.20 tons of methanol has been fully consumed, and a new lot of the same quantity is received. If the average daily demand (R) is 97.37 tons and the average lead time (L) is six days (Equation 35):

$$\boldsymbol{Seven\ days\ of\ demand} = \boldsymbol{Q} = R \times L \tag{35}$$

$$\boldsymbol{Q} = 97.37 \frac{ton}{day} \times 6.00\ days$$

$$\boldsymbol{Q} \cong 584.20\ ton$$

9) Based on the information and interpretation of the case, how can the average replenishment stock lot size be estimated in the context of purchasing on the spot market?

The objective is to maintain the lowest possible SS without compromising the operation's ability to meet demand. Section 5 of the case states that there are no fines or penalties in the commercial relationship between the biodiesel supplier and buyer, provided that at least 95% of the contracted volume is delivered. This is the minimum acceptable service rate (fr) in the biodiesel sales operation, which serves as a guideline for defining SS for methanol. Once the required fr for the operation is established, the expected amount of ESC can be estimated (Equation 36):

$$\boldsymbol{fr} = 1 - \frac{ESC}{Q} \tag{36}$$

$$95\% = 1 - \frac{ESC}{584.20} = \boldsymbol{ESC} \cong 29.21\ ton$$

An ESC of 29.21 tons indicates the average shortage per stock cycle (seven days) required to obtain an fr of 95%.

Knowing ESC corresponding to a 95% fr and the combined standard deviation of the lead time, the SS that allows this fr can be found through trial and error. By applying the ESC formula and starting with a randomly assigned SS, the SS that corresponds to an ESC of 29.21 tons can be obtained using the Excel "Goal Seek" tool. Assuming an initial SS of 200 tons, we have (Equation 37):

$$\boldsymbol{ESC} = -SS \times \left\{1 - NORM.DISTP.N\left(\frac{SS}{\sigma_L}; 1\right)\right\} + \sigma_L \times NORM.DISTP.N\left(\frac{SS}{\sigma_L}; 0\right)$$

$$\boldsymbol{ESC} = -200.00 \times \left\{1 - NORM.DISTP.N\left(\frac{200.00}{194.74}; 1\right)\right\} + 194.74 \times NORM.DISTP.N\left(\frac{200.00}{194.74}; 0\right) \tag{37}$$

With Goal Seek open:

- In the "Define cell" field, select the cell containing the ESC formula, which calculates ESC as a function of the randomly attributed SS.
- In the "value" field, enter the ESC value corresponding to an fr of 95% (ESC= 29.21 tons).
- In the "Altering cells" field, select the cell that holds the random SS value**.**

The result from the Goal Seek function indicates that, to achieve an ESC of 29.21 tons, the operation should maintain an SS of 130.70 (Equation 38).

$$29.21 = -130.70 \times \left\{1 - NORM.DISTP.N\left(\frac{130.70}{194.74}; 1\right)\right\} + 194.74 \times NORM.DISTP.N\left(\frac{130.70}{194.74}; 0\right) \tag{38}$$

10) Calculate the ROP and MS_T for the purchase operation via the spot market

(Equation 39):

$$\boldsymbol{ROP} = SS + R_L \tag{39}$$

$$\boldsymbol{R_L} = R \times L = 97.37 \frac{ton}{day} \times 6.00\ days \cong 584.20\ ton$$

$$\boldsymbol{ROP} = 130.70\ ton + 584.22\ ton \cong 714.90\ ton$$

MS_U (Equation 40):

$$\boldsymbol{MS_U} = \frac{Q}{2} + SS = \frac{584.20\ ton}{2} + 130.70\ ton \cong 422.80\ ton \tag{40}$$

MS_T (Equation 41):

$$\boldsymbol{MS_T} = MS_U + TB\boldsymbol{MS_T} = MS_U + TB \tag{41}$$

$$\boldsymbol{MS_T} = 422.90\ ton + 60\ ton \cong 482.80\ ton$$

11) Calculate CSL for the purchase operation via the spot market (Equation 42).

$$\boldsymbol{CSL} = NORM.DIST.N(x; mean; stand\_dev; 1) = NORM.DIST.N(ROP; R_L; \sigma_L; 1)$$

$$CSL = NORM.DIST.N(714.90; 584.20; 194.74; 1) \cong 99.92\% \quad (42)$$

12 Calculate the total cost of inventory associated with the purchase strategy via the spot market.

Total inventory cost (TC) comprises order costs (*order_cost*), inventory holding costs (*invent_hold_cost*), and material or product costs (*mat_cost*).

Order_cost comprises the quality checking costs (*qual_cost_yr*) (Equation 43).

$$order\_yr = \frac{R_{annual}}{Q} \quad (43)$$

$$order\_yr = \frac{97.37 \frac{ton}{day} \times 365\ days}{584.20\ ton} \cong 60.83\ orders\ per\ year$$

So, mathematically, *quali_cost_yr* is (Equation 44):

$$qual\_cost\_yr = order\_yr \times qual\_cost \quad (44)$$

$$qual\_cost\_yr = 60.83\ orders \times \frac{R\$2{,}000.00}{order}$$

$$qual\_cost\_yr \cong R\$121{,}666.67\ per\ year$$

and *order_cost* is (Equation 45):

$$order\_cost = qual\_cost\_yr \quad (45)$$

$$order\_cost \cong R\$121{,}666.67\ per\ year$$

Invent_hold_cost comprises financial costs (*fin_cost_yr*), monitoring costs through outsourcing (*monit_cost_yr*), and the apportioned fixed cost (*fc_app_yr*). These three expense items are detailed in Section 5.

To calculate *fin_cost_yr*, the cost of holding a ton of methanol in stock for a year must be determined. This requires first calculating the average price of methanol in R$/ton for the spot market context. This calculation uses the historical price of methanol FOB Santos, the evolution of the R$/USD exchange rate, and the history of the freight costs from Santos to Araguari. By subtracting the observed FOB Santos methanol price from the respective associated freight costs, and then dividing each result by the observed R$/USD ratio, the estimated price history, CIF Araguari, can be found in R$/ton. By calculating the averages of these prices, the estimated average price of methanol purchased via the spot market (C) can be found, which will serve as a reference for analyzing the costs associated with this strategy. Thus (Equation 46):

$$C = \frac{\left\{\sum_{i=1}^{n}\left[\left(\frac{FOB\ Price_1 - Freight_1}{exchange_1}\right) + \left(\frac{FOB\ Price_2 - Freight_2}{exchange_2}\right) + \dots \left(\frac{FOB\ Price_n + Freight_n}{exchange_n}\right)\right]\right\}}{n} \quad (46)$$

$$C \cong \frac{R\$4{,}130.82}{ton}$$

Based on the unit price of methanol and the company's cost of capital (CC), *fin_cost_unit* and, therefore, *fin_cost_yr* can be calculated (Equations 47 and 48).

$$fin\_cost\_unit = C \times CC \quad (47)$$

$$fin\_cost\_unit \cong R\$4{,}130.82 \times 15.5\%\ p.a. \cong R\$640.28\ per\ ton\ per\ year$$

$$fin\_cost\_yr = MS_T \times fin\_cost\_unit$$

$$fin\_cost\_yr = 482.80\ ton \times R\$640.28 \frac{ton}{year} \cong R\$309{,}125.89\ per\ year \quad (48)$$

Monit_cost_yr is a function of MS_T and the inventory monitoring charge (*monit_cost,* Section5). Therefore (Equations 49 and 50):

$$monit\_cost = R\$100.00\ per\ ton\ per\ month \quad (49)$$

$$monit\_cost = R\$100.00 \times 12 = R\$1{,}200.00\ per\ ton\ per\ year$$

$$monit\_cost\_yr = MS_T + monit\_cost \quad (50)$$

$$monit\_cost\_yr = 482.80\ ton \times \frac{R\$1{,}200.00}{year} \cong R\$579{,}360.54$$

Fc_app_yr is a function of MS_T and the apportioned fixed cost (*fc_app*, Section 5) (Equations 51 and 52).

$$fc\_app = R\$150.00\ per\ ton\ per\ month \quad (51)$$

$$fc\_app = R\$150.00 \times 12 = R\$1{,}800.00\ per\ year$$

$$fc\_app\_yr = MS_T \times fc\_app \quad (52)$$

$$fc\_app\_yr = 482.80\ ton \times R\$1{,}800.00 \frac{ton}{year} \cong R\$869{,}040.81$$

Having determined *fin_cost_yr, monit_cost_yr*, and *fc_app_yr*, *invent_hold_cost* can be calculated (Equation 53):

$$invent\_hold\_cost = fin\_cost\_yr + monit\_cost\_yr + fc\_app\_yr \quad (53)$$

$$invent\_hold\_cost = R\$309{,}125.19 + R\$579{,}360.54 + R\$869{,}040.81$$

$$invent\_hold\_cost \cong R\$1{,}757{,}527.25$$

Mat_cost is calculated as follows (Equation 54):

$$mat\_cost = R \times C \quad (54)$$

$$mat\_cost = 97.37 \frac{ton}{day} \times 365\ days \times \frac{R\$4{,}130.82}{ton}$$

$$mat\_cost \cong R\$146{,}803{,}710.36$$

To calculate TC (Equation 55):

$$\boldsymbol{TC} = order\_cost + invent\_hold\_cost + mat\_cost \quad (55)$$

$$\boldsymbol{TC} = R\$121{,}666.67 + R\$1{,}757{,}527.25 + R\$146{,}803{,}710.36 = R\$148{,}682{,}904.27$$

9.4. Group 4: strategy based on economic order quantity

13 An evaluation of the strategy based a long-term contract showed that the current operation has an fr of 99.88%. However, maintaining this level requires operating with high SS values.

To assess this strategy using EOQ, the data presented or calculated for the long-term purchase contract strategy will be used. The EOQ should result in the smallest possible TC, considering an fr of 95%. This problem can be solved using Excel's Solver.

First, a random lot size value (Q) must be assigned. This value, along with the other assumptions, will be used to calculate a random TC (Equation 56):

$$\boldsymbol{TC} = order\_cost + invent\_hold\_cost + mat\_cost\ (as\ a\ function\ of\ the\ size\ of\ a\ random\ lot\ Q) \quad (56)$$

To model the problem in Solver, the following should be considered:

Step 1: Define the objective cell (objective cell = TC).

Step 2: Select "minimum" to find the smallest TC.

Step 3: Define the variable cells (variable cell = Q).

Step 4: Establish restrictions (fr≥ 95%).

Step 5: Select the nonlinear GRG solution method.

Step 6: Run the model.

The answer will be the following:

$$\boldsymbol{Q} = 261.74\ tons$$

$$\boldsymbol{TC} = R\$152{,}542{,}239.47$$

10. BRIEF REVIEW OF THE LITERATURE AND THE INDICATED BIBLIOGRAPHY

This teaching case was designed as a tool for consolidating students' understanding of inventory management techniques, a key aspect of supply chain management. Specifically, it seeks to expose students to the application of the cycle inventory model (with a focus on economies of scale) and safety stock model (with a focus on availability level). Teachers, therefore, must address, *a priori,* the conceptual aspects and mathematical formulas underlying these models. Below, we indicate some references that address these concepts theoretically and explain how they are calculated. We specifically recommend Chopra and Meindl (2016) to help with mathematical formulation.

Chopra, S., & Meindl, P. (2016). *Gestão da Cadeia de Suprimentos: estratégia, planejamento e operação*. Pearson Education do Brasil.

Empresa de Energia Elétrica (EPE) (2019). *Competitividade do Gás Natural*: *Estudo de Caso na Indústria de Metanol*. Ministério de Minas e Energia.

Hammond, J. H. (2018). Operations Management: Managing Inventory. In R. Shapiro (Ed.). *Core Curriculum* (pp. 1-34). Harvard Business Publishing Education.

Prater, E., & Whitehead, K. (2013). Inventory Management. In E. Prater & K. Whitehead (Eds). *An introduction to supply chain management: a global supply chain perspective* (pp. 60-80). Business Expert Press LLC.

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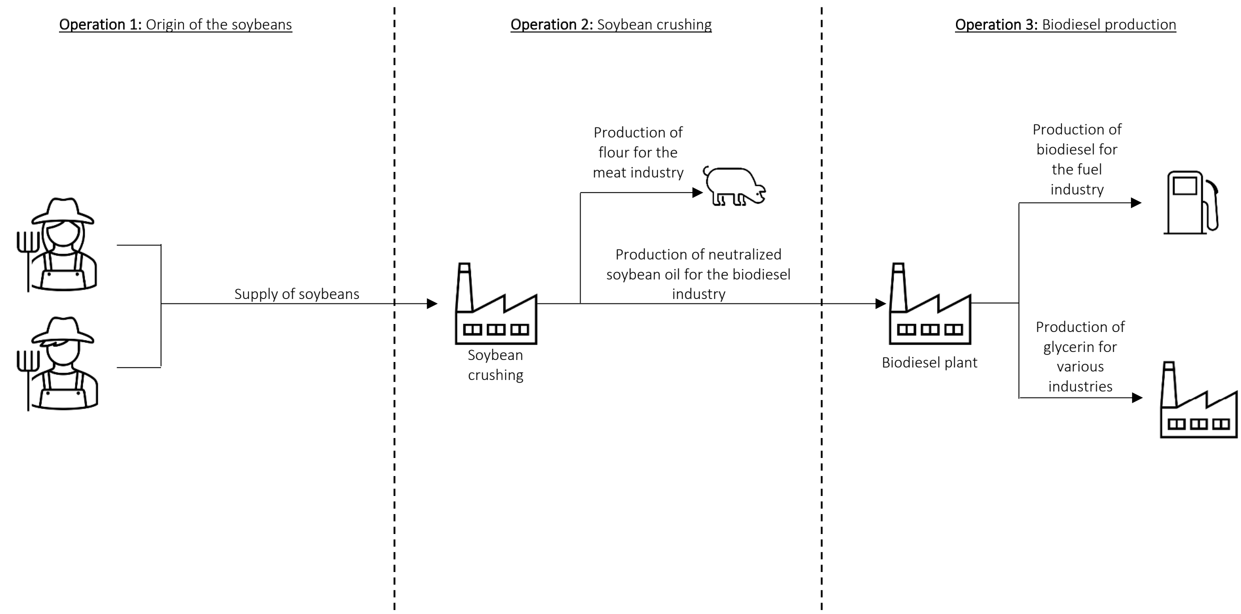
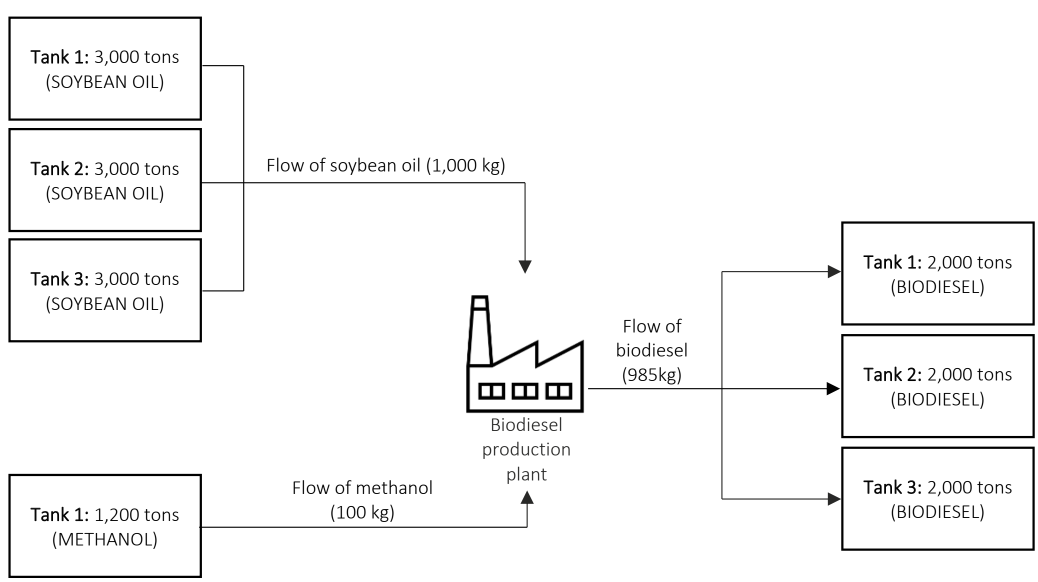
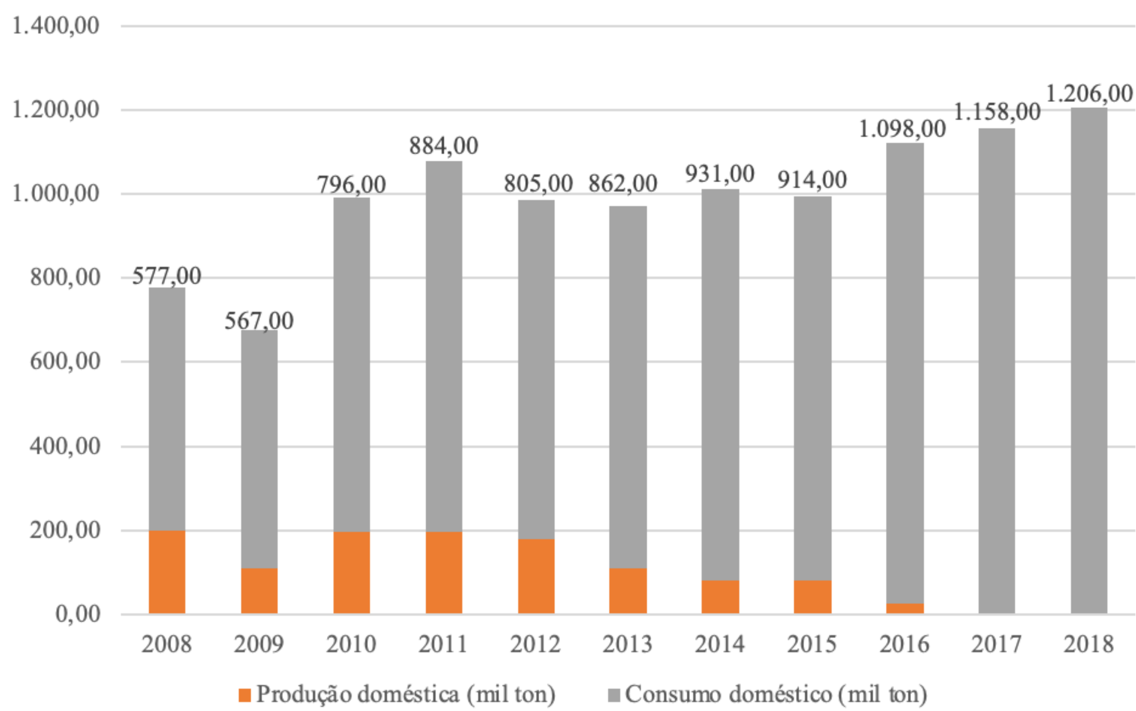


Appendix 1. Flowchart of the industrial operation of the Nobre Group in Araguari.



Appendix 2. Nobre Group’s biodiesel production flow.



Source: EPE (2019). *Competitividade do Gás Natural*: *Estudo de Caso na Indústria de Metanol*. Brasília: Ministry of Mines & Energy.

Appendix 3. Annual consumption of methanol in Brazil.

Appendix 4. Daily time series of biodiesel production.

Date	Production (tons)
05/01/2021	970
05/12/2021	956
05/03/2021	958
05/04/2021	949
05/05/2021	957
05/06/2021	968
05/07/2021	970
05/08/2021	962
05/09/2021	946
05/10/2021	945
05/11/2021	969
05/12/2021	954
05/13/2021	958
05/14/2021	948
05/15/2021	975
05/16/2021	961
05/17/2021	956
05/18/2021	947

Continues...

Appendix 4. Continuation

Date	Production (tons)
05/19/2021	945
05/20/2021	948
05/21/2021	947
05/22/2021	957
05/23/2021	959
05/24/2021	964
05/25/2021	960
05/26/2021	946
05/27/2021	955
05/28/2021	959
05/29/2021	957
05/30/2021	965
05/31/2021	970
06/01/2021	946
06/02/2021	954
06/03/2021	961
06/04/2021	963
06/05/2021	966
06/06/2021	968
06/07/2021	967
06/08/2021	967
06/09/2021	956
06/10/2021	950
06/11/2021	948
06/12/2021	962
06/13/2021	958
06/14/2021	946
06/15/2021	961
06/16/2021	960
06/17/2021	964
06/18/2021	957
06/19/2021	968
06/20/2021	960
06/21/2021	964
06/22/2021	946
06/23/2021	960
06/24/2021	975
06/25/2021	948
06/26/2021	970

Continues...

Appendix 4. Continuation

Date	Production (tons)
06/27/2021	948
06/28/2021	964
06/29/2021	959
06/30/2021	949
07/01/2021	958
07/02/2021	971
07/03/2021	975
07/04/2021	957
07/05/2021	974
07/06/2021	956
07/07/2021	967
07/08/2021	961
07/09/2021	956
07/10/2021	961
07/11/2021	963
07/12/2021	945
07/13/2021	966
07/14/2021	945
07/15/2021	958
07/16/2021	971
07/17/2021	961
07/18/2021	973
07/19/2021	964
07/20/2021	973
07/21/2021	968
07/22/2021	952
07/23/2021	958
07/24/2021	973
07/25/2021	969
07/26/2021	961
07/27/2021	952
07/28/2021	964
07/29/2021	951
07/30/2021	950
07/31/2021	948
08/01/2021	947
08/02/2021	961
08/03/2021	963

Continues...

Appendix 4. Continuation

Date	Production (tons)
08/04/2021	955
08/05/2021	968
08/06/2021	963
08/07/2021	973
08/08/2021	949
08/09/2021	953
08/10/2021	965
08/11/2021	967
08/12/2021	967
08/13/2021	964
08/14/2021	957
08/15/2021	955
08/16/2021	975
08/17/2021	953
08/18/2021	957
08/19/2021	962
08/20/2021	949
08/21/2021	963
08/22/2021	963
08/23/2021	945
08/24/2021	947
08/25/2021	949
08/26/2021	969
08/27/2021	948
08/28/2021	957
08/29/2021	954
08/30/2021	973
08/31/2021	946

Continues...

Appendix 5. Time series of average monthly methanol prices: Cost, Insurance, and Freight Araguari (R$/ton), Free on Board at the port (USD/ton), average monthly amount in USD, and average monthly freight charges from Santos to Araguari.

Date	Prices in R$/ton, CIF Araguari – exclusive supplier	Prices (USD/ton), FOB Santos	R$/USD	Santos-Araguari freight (R$/ton)
March-19	4,635	1,013.80	3.72	616
April-19	3,694	900.71	3.83	374
May-19	3,658	813.45	3.87	502
June-19	4,862	998.12	4.00	448
July-19	5,000	1,079.98	3.88	563
Aug-19	4,893	1,097.87	3.75	533
Sept-19	4,922	1,008.09	4.02	443
Oct-19	4,048	923.87	4.06	326
Nov-19	3,963	783.29	4.15	520
Dec-19	3,738	745.47	4.18	462
Jan-20	3,641	722.68	4.09	645
Feb-20	4,322	987.01	4.16	370
March-20	3,781	731.41	4.32	492
April-20	4,564	884.98	4.74	421
May-20	4,769	823.87	5.26	425
June-20	3,845	597.65	5.82	380
July-20	3,754	642.71	5.19	340
Aug-20	4,064	650.22	5.35	586
Sept-20	3,769	620.68	5.39	419
Oct-20	4,219	632.98	5.27	617
Nov-20	4,410	663.21	5.62	320
Dec-20	3,837	579.87	5.49	544
Jan-21	4,239	720.87	5.10	399
Feb-21	4,621	743.86	5.27	498
March-21	4,628	776.54	5.38	443
April-21	4,770	721.76	5.63	620
May-21	4,999	745.89	5.62	627
June-21	4,830	765.32	5.27	566
July-21	3,696	589.76	5.09	457
Aug-21	3,504	587.32	5.10	438

CIF: Cost, Insurance, and Freight; FOB: Free on Board.

Appendix 6. Lead times of a large trading company that operates in the spot market.

Order date	Delivery date
02/01/2021	02/04/2021
02/08/2021	02/13/2021
02/18/2021	02/25/2021
03/03/2021	03/09/2021
03/13/2021	03/16/2021
03/21/2021	03/30/2021
03/25/2021	04/04/2021
04/03/2021	04/09/2021
04/10/2021	04/15/2021
04/14/2021	04/20/2021
04/21/2021	04/27/2021
04/27/2021	05/04/2021
05/05/2021	05/12/2021
05/11/2021	05/19/2021
05/20/2021	05/22/2021
05/23/2021	05/28/2021
05/30/2021	06/04/2021
06/04/2021	06/12/2021
06/11/2021	06/18/2021
06/18/2021	06/22/2021
06/21/2021	06/28/2021