RESEARCH ARTICLE OPEN ACCESS

THE IMPACT OF THE OPERATING EFFICIENCY ON THE BULLWHIP EFFECT

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ABSTRACT
This paper aims to verify the impact of factors related to the operational efficiency in the industry along a supply chain, as well as their relation with the bullwhip effect.To verify the proposal, we used a generic supply chain that was modeled mathematically as a problem of maximum flow to meet the demand. At the same time, we calculated its global reliability through the Reliability Block Diagram method.We compared the results of the reliability of operations and the bullwhip effect dimension and we arrived at a consistent causal relation. Through a correlation of -0.97, we could attest that the higher the reliability along the parts of the chain, the increased bullwhip effect. Despite being developed for the specific chain of palm oil products, the test can be replicated for other supply chains. As a possibility for future studies, we suggest a comparative study using different types of chains and the same basic methodology. The consistency and relevance of the research is in the search for new causes to explain the bullwhip effect, which is closely linked by the researchers of the area to the demand uncertainty and inconsistency of the upstream flow of information in the chain. This study starts with the assessment of the operating efficiency, regarding the reliability of the members of the chain as a cause for the generation of the bullwhip effect. This way, the methodology used also brings a unique application to calculate the bullwhip effect, through the modeling of a network problem and uses the reliability block diagram to calculate the overall reliability of a supply chain.

***Keywords*–**Maintenance. TPM. RCM. Reliability. Systematic Comparison. Productivity. Literature Review.

Date of Submission: 03-07-2022 Date of Acceptance: 16-07-2022

I. INTRODUCTION

The strategy of companies is getting increasingly complex, not being limited anymore to only one dimension of generic strategy, including several aspect such as cost leadership, differentiation and targeting (PORTER, 1996). The management of information in the supply chain has become an indispensable factor in the management and competitiveness of corporations. During the mid-twentieth century, the competition was mainly among organizations in segments of their own markets. However, currently, this reality has changed. With the information age, the outsourcing of operations and the globalization of operations, the competition started to be among supply chains (CHRISTOPHER, 2010). In this scenario, the three dimensions of Porter's competitive strategies must be taken into consideration, rising the complexity of the management (PORTER, 1989).

One of the main challenges in the supply chain management is to minimize the bullwhip effect, which is the difference in demand between the ends of the chain, we mean the supplier end-customer path. In the literature, the main causes of the bullwhip effect are related to the uncertainty of the demand and the poor flow of information in the links of the supply chains.

One of the successful stories in the supply chain management is addressed to the world's largest retailer, Wal-Mart, which manages to maintain a flow of information in its vast and complex chain with real-time delivery of demand forecasts in the short-, medium- and long-term to its suppliers, causing them to reduce the uncertainty, which entails the reduction of inventories and costs. Along with the information management, Wal-Mart, has a high operational efficiency and also imposes it to its suppliers inducing to lower product prices, in order to compete primarily in the cost dimension (buyer’s bargaining power) (WALTON, 1992; STRACHAN, 1994; GRANT, 2010).

In order to maintain the continuous flow of demand along its supply chain, Wal-Mart invests in integrated information management regarding demand and reliability of the links in the chain, controlling the operational efficiency. In the other hand, the main causes of the bullwhip effect restrictions described in the literature are the uncertainty of the demand and the deficiency in information management.

Aware of the high competition of the business environment in the global world, most companies try to increase their productivity and eliminate the problems of their supply chain systems, similarly to what Wal-Mart does. Some of the problems that companies face are the excessive inventories, lack of products, distortion of information and inadequate transport. One of the main reasons for these problems is the "bullwhip effect". The bullwhip effect is the amplification of the demand variance in relation to the customer's requests and the requests that arrives at the supplier, evident distortions among the links in the chain (LEE et al., 1997).

In this context, this article addresses the "operational efficiency" factor to assess its impact on the bullwhip effect from the point of view of the operation and maintenance management. In addition to the deficiency in the flow of information and the uncertainty of demand, we assume the the hypothesis that the operational efficiency of the stages of production and logistics of a supply chain impacts on the generation of the bullwhip effect, and also that the overall operational efficiency of a chain can be measured and converted into operational reliability; related to availability, performance, product quality and compliance with deadlines.

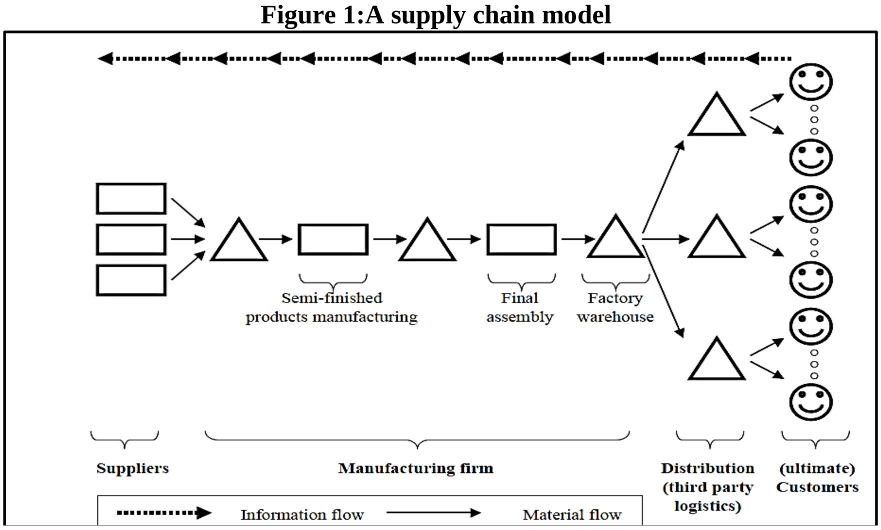
Therefore, we will try to understand the impact that the operational efficiency of a supply chain has on the bullwhip effect. In addition to the central objective of the research, we will try to answer some questions inherent to the subject of the work: how can we measure the overall reliability of a supply chain? Taking into account the bullwhip effect, in quantitative terms, how do we evaluate the impact of the operational efficiency as the translation of the operational reliability of the stages of production and logistics?

In synthesis, we aim to verify the relation between global reliability of a chain and the generation of the bullwhip effect, to model mathematically a supply chain in the light of a problem of networks in an attempt of minimizing the amount produced by suppliers, through demands required in each step, and to propose a way to measure the overall reliability of the supply chain through the Reliability Block Diagram (RBD) method.

II. SUPPLY CHAIN AND THE BULLWHIP EFFECT

For Christopher (2010, p. 12), a supply chain is a network of organizations with activities and processes involved in the generation of value in the form of products and services to customers. Mentzer et al. (2001, p. 48), define the supply chain as "a systematic and strategic coordination of the traditional managerial functions, and of the tactics existent among them within a company, and among companies within the supply chain, to improve separately the companies long-term performance and the chain as a whole." Towards the formation of value, we have the products ranging from suppliers to customers, and according to the demand, we have the inverse flow of information (Figure 1).

Figure 1:A supply chain model



Source: Zsidisin and Ritchie (2009).

Krajewski et al. (2009) defines operational efficiency as the performance of the stages of production and logistics activities using resources optimally and economically. Krajewski et al. (2009) defends the importance of the integration of a supply chain in the reliability of the flow of information and of the products and services. The author also says that the supply chain risks are associated with not only the operational efficiency, but with the orientation of the companies in relation to customers, neglecting the flow of information to the suppliers.

The collaboration among organizations is a necessity for an efficient supply chain. The supply chain is considered as a cross between a pure market interaction and a hierarchy where the combination of the best features from both isthe goal. Ideally, each entity within a supply chain will focus on its core competencies. Thus, the competition among the members along the supply chain is replaced by a commitment to improve the competitiveness of the supply chain as a whole (ZSIDISIN, RITCHIE, 2009).

For the definition of a strategy to make the supply chain competitive, it is important to establish the business and stages involved in the supply chain management (CHRISTOPHER et al., 2006). Chopra and Meindl (2007) state that the supply chain strategies determine the types of material acquisition and its transport, and also the product manufacturing or the service creation, and the distribution in the case of a product. Business processes are activities that produce a specific result for a customer in terms of value, but it requires the second level of the supply chain management, which includes the components such as the structures, resources, knowledge, skills, people, and instances of power and leadership that synergistically support the business processes (PIRES, 2009).

The complexity of the operations and interrelations in the supply chains generates risks that Zsidisin and Ritchie (2009) categorized in four major dimensions:

- *Interruptions for the supply of goods or services*, including poor quality, which causes downtime and consequent inability to satisfy the customer needs in time.
- *Prices volatility* can result in difficulties in the transmission of price changes to the customer and has potential consequences in lost profit.
- *Poor quality products or services*, either upstream or downstream, can have an impact on the level of customer satisfaction, with consequences for future revenue and, possibly, immediate claims for financial compensation.
- The *company's reputation* can represent risks, often generated by issues not directly related to the supply chain itself.

The interrelation between the processes intrinsic to the chain presents some complex aspects that generate dysfunctions in global operations. One of the most notorious deviations and irregularities that can be verified in a chain is the occurrence of the "bullwhip effect" (LEE, 1997; CACHON, 2006; BALLOU, 2011).

III. OPERATIONS AND MAINTENANCE MANAGEMENT

The management aims to ensure the implementation of the company’s objectives by the integrated use of resources. The operation management defines and applies the necessary procedures for the processing of materials, information and knowledge into products and services, adding value to them, using the resources available in a predetermined time horizon (SLACK et al., 2009).

Krajewski et al. (2009) assure that the production horizon includes the choice of the industrial layout, the capacity management, the process optimization by the sizing and sequencing of production, the inventory management, and demand forecasting. It also aggregates the management of machinery and equipment to the production, in relation to issues such as product maintenance, reliability, quality, and process efficiency.

Linked to the manufacturing operation management, there is the maintenance management, which seeks to ensure that the defined production system is operated according to the required specifications. Fernández and Márquez (2012) defines maintenance as the combination of all the managerial techniques and actions during the life cycle of an item, which ensure its full operation for the required function. For Manzini and Ferrari (2010), maintenance is the function that monitors and maintains facilities, equipment and working environments. It must architect, organize, perform and verify the work to ensure the nominal operation of the item during the determined periods of work and minimize stop intervals caused by malfunctions or resulting repairs.

Therefore, the maintenance management is the proper management of failures, availability and performance of the physical assets of an organization, so that they work according to the expected requirements during their life cycle. The maintenance strategies are the different types of tasks, including actions, procedures, resources and time. These activities must be performed in accordance with the defined schedule in order to ensure the maintenance of the target-assets (MÁRQUEZ, 2007).

According to Assis (2010), with the constant technological advances, the manufactures increasingly need support to maintain the efficiency of their assets. In corporative environments, the maintenance function has the great challenge of accompanying this advancement using the background knowledge and modern management tools. Among maintenance policies emphasized in recent decades, we highlight the Total Productive Maintenance (TPM) and the Reliability Centered Maintenance (RCM).

For Dale (2011), TPM is an extension of the Japanese philosophy TQM (Total Quality Management), which points out the eliminating of losses,while as mentioned in the NASA Guide (2000), the RCM uses quantitative analysis and methods in order to increase the probability of a physical component or system working as designed in its life cycle and with the minimum of maintenance.

According to Lopes (2012), TPM is an equipment maintenance policy that involves workers from all areas of the company, especially engineering, maintenance and operation. It has the dual purpose of achieving zero faults (equipment) and zero defects (products). Because of the elimination of faults and defects, the availability of equipment can be increased, costs can be reduced, as well as inventories (stocks), and so labor productivity can be increased.

In the application of the TPM policy, a feedback system is implemented in order to facilitate the assessment of the whole system. This tool receives the name of OEE (Overall Equipment Effectiveness). The OEE is an indicator that approaches the efficiency of a particular manufacturing operation, with the aim of helping the search of processes problematic areas, providing the answers for possible improvements (LUCATELLI, 2002). This indicator is obtained as showed in the Equation 01 (ASSIS, 2010):

$$\boldsymbol{OEE}(\%) = \boldsymbol{availability}(\%) \times \boldsymbol{performance}(\%) \times \boldsymbol{quality}(\%) \quad \text{Eq. 01}$$

According to Amorim (2009), the OEE measures the performance in three dimensions, as it considers the machine available time for production, the efficiency demonstrated during the production, and the level quality obtained in the products processed in the equipment. The OEE seeks to establish the impact of the six major losses elucidated by the TPM, as presented in Figure 02:

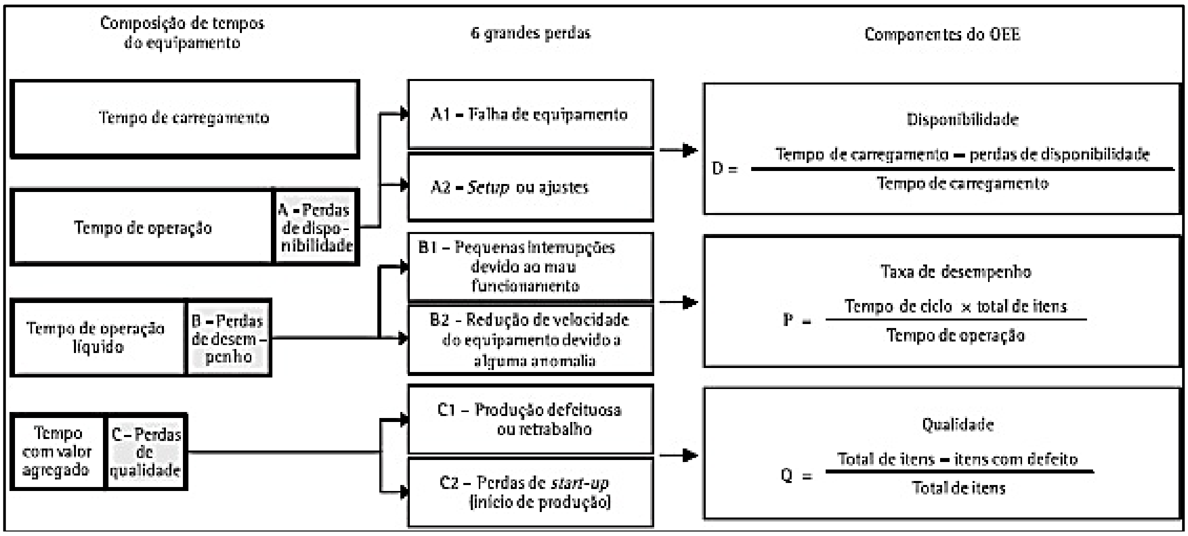


Figure 02:Elements of the Overall Effectiveness of a System
Source: BRAGLIA et al. (2009).

Legenda: Composition of times of the equipment; Charging time; Time of operation; Loss of availability; Net operating time; Performance losses; Value-added time; Loss of quality; Six big losses; Equipment failure; Setup or adjustments; Short interruptions due to malfunction; Speed reduction of the equipment due to an anomaly; Faulty production or rework; Loss of star-up (start of production); OEE components; Availability; Charging time – loss of availability; Charging time; Performance rate; Cycle time X total items; Time of operation; Quality; Total items – defective items; Total items.

As the OEE is composed of three indicators, the losses inherent in each indicator directly affect its value(Figure 2), and so the global index aims to expose the impact of each of the seven failures in the overall efficiency.

Therefore, a diagnostic indicator also serves as a development and improvement goal for a particular production process.

The RCM and the TPM are two systems respected in the academy, and frequently applied in the corporations. The RCM maintenance system is defined by Moubray (2012) as a process used to determine what must be done to ensure that any physical item continue to perform the functions required by its users in its current operational context. For this purpose, MENDES, 2011 mentions that is necessary to answer seven basic questions of the item under analysis:

1. What are the roles and the standards of performance of the items in their current operational context?
2. How they fail to fulfill their functions?
3. What are the causes of each functional failure?
4. What happens when each failure happens?
5. What are the consequences of each failure?
6. What can be done to predict or prevent each failure?
7. What should be done if there is no suitable preventive task?

Smith (1993, p. 6), one of the pioneers in the application of RCM in the '80s, proposed that "the central objective of the RCM is to establish a systematic process of analysis that allows the definition of maintenance tasks of any physical item in order to guarantee the operational safety and reliability at the lowest possible cost", it means to preserve the functions of the system, to identify failure modes, to determine the importance of failures and to select more effective and applyable planned maintenance activities. To establish such objectives, the author proposes the application of seven steps.

The RCM operates in several dimensions of the industrial management, especially concerning the reduction of the life-cycle cost of equipment. This system operates directly on the study and assessment of the equipment failure modes, on the ability of developing something (capability), i.e. work regularly with minimal intervention, and on the forecast and study of failures regarding reliability.

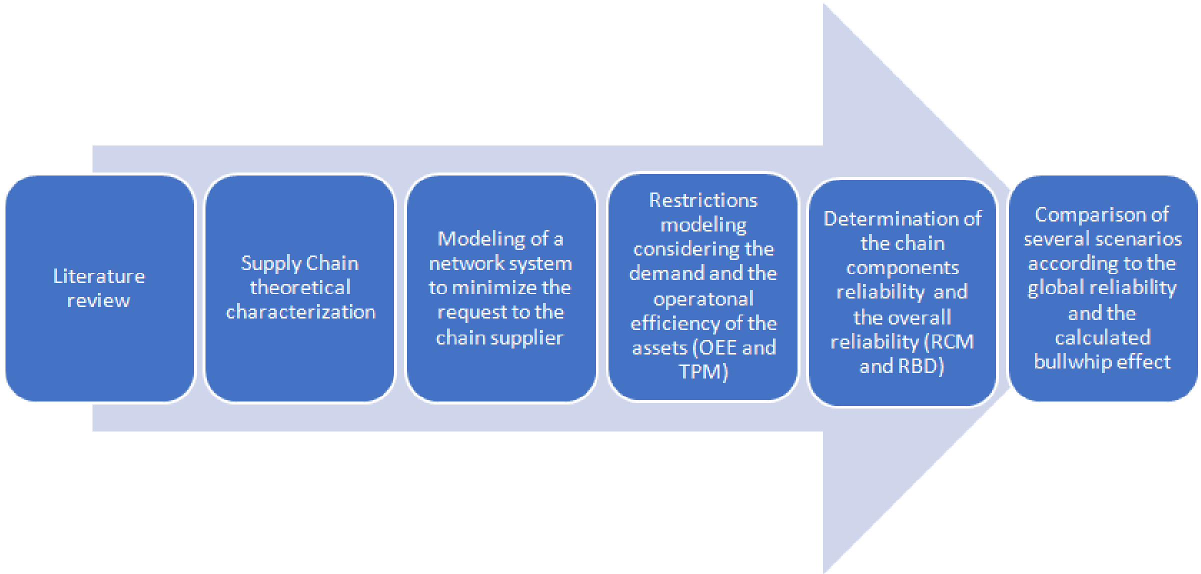
IV. Research Methodology

This is a applied survey, which aims to analyze the impact of the operational efficiency in the generation of the bullwhip effect in supply chains. It is an exploratory research as it seeks to approximate the concepts of operation and maintenance management to the risks in the supply chain. Thus, we seek to use the equipment reliability studies to understand the reliability of a supply chain. The research is quantitative, as it proposes a global indicator of reliability in the chain, and qualitative, as it uses the theoretical understanding of supply chain and maintenance management elements. The method used is created from the construction of scenarios varying the overall efficiency, which uses the network optimization to infer the impact of the bullwhip effect on the production.

The research approaches the literature on maintenance management, reliability engineering and risk management in the supply chain, aiming to verify the impact generated by the operations and maintenance management considering loss of availability, performance and quality. At this point, the research show the generic components of a supply chain, following the sequence: supplier – producer – distributor – customers.

With the theoretical study, we will determine processes intrinsic to the maintenance and the impact generated in the supply chain. The study will use a technique derived from the management of reliability, named RBD (Reliability Block Diagram). The methodology is suitable to determine the reliability of the components of the chain at the level of availability of resources and equipments, process performance, and quality of final products. The reliability of the components can be divided into three parts: the OEE of each step, by determining bottlenecks; the calculation of the indicator of efficiency, and the establishment of the safety factor coupled to stocks. The size of the request will be calculated using a model of flow network to minimize the size of the request in the supplier, whose comparison with the customer request provides the dimension of the bullwhip effect. Finally, the research will compare the size impact of the bullwhip effect on the overall efficiency of the chain in various scenarios.

Figure 03:Stages of the research



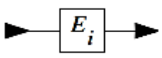
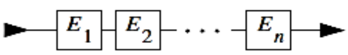
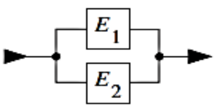
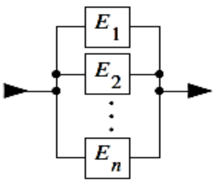
Source: Own elaboration (2014)

The stages of the work (Figure 04) seek results for the overall objective and the specific goals outlined. It is also the strategy adopted for the research development

4.1 Reliability Block Diagram (RBD) Method

The Reliability Block Diagram (RBD) is a technique of reliability engineering and RCM that evaluates the overall reliability of a system as a whole, and not the reliability of individual parts. We assume that the systems has flows, elements in series, and redundancies, elements in parallel and so we can calculate the overall reliability of a complex system, similarly to the method used in determining resistances in electrical circuits (VERMA et al., 2010).

Figure 4:Calculation of the reliability in complex systems

Reliability Block Diagram	Reliability Function ($R_S = R_{S0}(t)$; $R_i = R_i(t)$, $R_i(0)=1$)	Remarks
 1	$R_S = R_i$	One -item structure, $\lambda(t)=\lambda \Rightarrow R_i(t)=e^{-\lambda_i t}$
 2	$R_S = \prod_{i=1}^{n} R_i$	Series structure, $\lambda_S(t)=\lambda_1(t)+\ldots+\lambda_n(t)$
 1-out-of-2 3	$R_S = R_1 + R_2 - R_1 R_2$	$1-$out$-$of$-2-$redundancy, $R_1(t)=R_2(t)=e^{-\lambda t}$ $\Rightarrow R_S(t) = 2e^{-\lambda t} - e^{-2\lambda t}$
 *k*-out-of-*n* 4	$E_1 = \ldots = E_n = E$ $\rightarrow R_1 = \ldots = R_n = R$ $R_S = \sum_{i=k}^{n} \binom{n}{i} R^i (1-R)^{n-i}$	k - out - of - n redundancy for $k = 1$ $\Rightarrow R_S = 1-(1-R)^n$ see p. 44 for $E_1 \neq \ldots \neq E_n$

Source: Birolini (2014).

The calculus procedure for the systems in series and parallel refers to the calculation of the resistance of electrical circuits (Figure 03). Elements in series tend to reduce the overall reliability, while elements in parallel (redundancies) tend to increase it.

4.2 Network Optimization

To meet the demand, every chain needs the upstream supply of raw materials. In order to model this problem mathematically, the network optimization can be effective as a maximum flow problem (Figure 5). At maximum flow problems, there are two special nodes: source node and terminal node. With the resolution of the maximum flow problem, we intend to determine the maximum amount of flow units that can be sent from a source node S to a terminal node T (THOMAS et al, 2001). The following table lists algorithms for solving the maximum flow problem.

Table 01: algorithms for solving the maximum flow problem

Method	Complexity	Description
Linear programming		Constraints given by the definition of a legal flow. See the linear program here.
Ford–Fulkerson algorithm	$O(E \max\|f\|)$	As long as there is an open path through the residual graph, send the minimum of the residual capacities on the path. The algorithm works only if all weights are integers. Otherwise, it is possible that the Ford–Fulkerson algorithm will not converge to the maximum value.
Edmonds–Karp algorithm	$O(VE^2)$	A specialization of Ford–Fulkerson, finding augmenting paths with breadth-first search.
Dinitz blocking flow algorithm	$O(V^2E)$	In each phase the algorithms builds a layered graph with breadth-first search on the residual graph. The maximum flow in a layered graph can be calculated in $O(VE)$ time, and the maximum number of the phases is n-1. In networks with unit capacities, Dinic's algorithm terminates in time.
General push-relabel maximum flow algorithm	$O(V^2E)$	The push relabel algorithm maintains a pre-flow, i.e. a flow function with the possibility of excess in the vertices. The algorithm runs while there is a vertex with positive excess, i.e. an active vertex in the graph. The push operation increases the flow on a residual edge, and a height function on the vertices controls which residual edges can be pushed. The height function is changed with a relabel operation. The proper definitions of these operations guarantee that the resulting flow function is a maximum flow.
Push-relabel algorithm with FIFO vertex selection rule	$O(V^3)$	Push-relabel algorithm variant which always selects the most recently active vertex, and performs push operations until the excess is positive or there are admissible residual edges from this vertex.
Dinitz blocking flow algorithm with dynamic trees	$O(VE \log(V))$	The dynamic trees data structure speeds up the maximum flow computation in the layered graph.
Push-relabel algorithm with dynamic trees	$O(VE \log(V^2/E))$	The algorithm builds limited size trees on the residual graph regarding to height function. These trees provide multilevel push operations.
Binary blocking flow algorithm	$O(E \min(V^{2/3}, \sqrt{E}) \log(V^2/E) \log U)$	The value U corresponds to the maximum capacity of the network.
MPM (Malhotra, Pramodh-Kumar and Maheshwari) algorithm	$O(V^3)$	Refer to the Original Paper.
Jim Orlin's + KRT (King, Rao, Tarjan)'s algorithm	$O(VE)$	Orlin's algorithm solves max-flow in O(VE) time for m\leq O(n^{(16/15)-\e}) while KRT solves it in O(VE) for m> n^{1+e}

Source: Goldberg and Rao (1998); Schrijver (2002); Kelner et al (2014)

In this paper we will use the linear programming. Based on a targeted network G = (V,A) with arches capacitated superiorly (denoted by u_{ij}), without ties, and associating to each arc (i,j) a value x_{ij} corresponding to the amount of flow traveled in the arc (i,j), the problem of maximum flow has to satisfy the constraints of a nonnegative arc ($x_{ij} \geq 0$), the capacity constraints in the arc ($x_{ij} \leq u_{ij}$) and the rule of conservation of flow on each node ($\sum_i x_{ij} = \sum_k x_{jk}$).That is, the flow that goes into each node and what is locally generated is equal to what comes out and what is locally consumed (HERNANDEZ et al., 2006).

Figure 5:Generic modeling of the maximum flow problem of networks

$$
\begin{array}{lll}
Max & & v \\
s.a. & \sum_{j:(i,j)\in A} x_{ij} - \sum_{j:(i,j)\in A} x_{ji} = & \begin{cases} v, & i = s \\ 0, & \forall i \in V - \{s,t\} \\ -v & i = t \end{cases} \\
 & 0 \leq x_{ij} \leq u_{ij} & (i,j) \in A
\end{array}
$$

Source: Brandão (2008)

In this generic representation, v is the maximum amount of flow that can pass the network G of source node s and target node t.

One of the restrictions set forth in the model of the maximum flow problem required that all flows were positive or zero (xij ≥ 0). In addition, indeed, in the final solution such restriction must always happen. However, the final solution is obtained by adding several streams that we inject in the network. Some of these flows may cross some line in contrast the indicated direction, in which case be counted as negative. The result (sum of all flows that were injected into the branch) which is has to be null or positive. In the background, a "negative" flow is an alternative an artificial mathematical trick to enable the exception of the algorithm (TAHA, 1997; DOLAN, 1993).

V. SUPPLY CHAIN MODEL

5.1 Characterization of the chain

We validated the research with an analysis of a palm supply chain for the production ofoleins, margarines and vegetable oils to supply the industrial segments of cosmetics and food. The choice of this supply chain was conditioned by the knowledge regarding it, taking into consideration the empirical experience and studies developed under the logistics area. However, it is worth noting that the proposed modeling structure for the network problem and the overall reliability of the chain by the block diagram can be generalized to other supply chains.

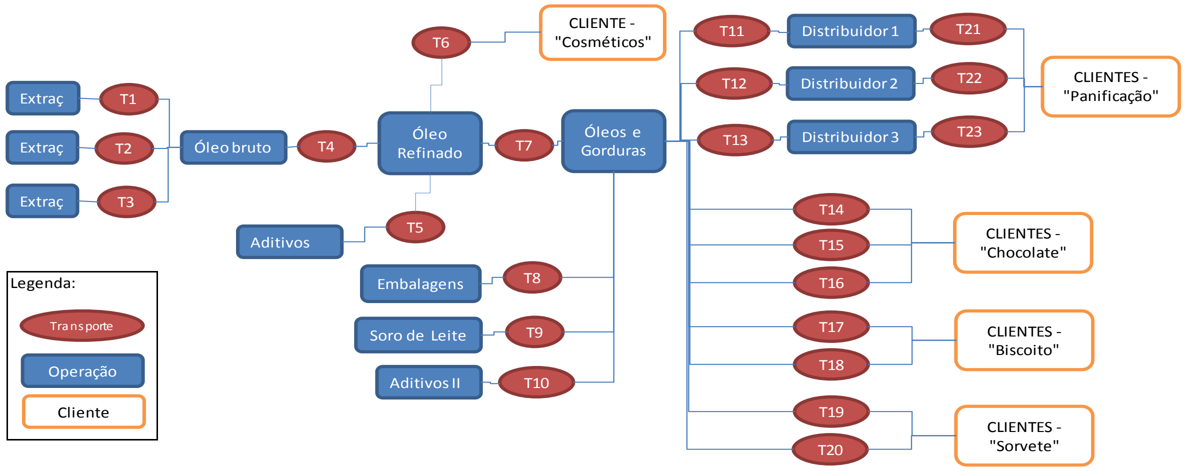
The palm productive chain (Figure 5), excluding the production of biofuels, begins with the extraction of palm in order to obtain the crude oil. Then, this crude oil is transported to the refining, where it receives additives. This refined oil may be sold in bulk to the cosmetics industry or sent to the production of oleins, margarines and fats. At this phase, which requires a specific packing that can be a box, a bucket, a barrel, a bag or a 'big bag', other specific additives are added, as well as whey. The finished product is sent to customers. However, for the bakery sector, there are intermediary distributors in the process.

For the model that supports the modeling of the research, we used a chain where the phases ranging from the extraction to the processing of refined oil into oleins, margarines and fats is situated in the Northern region, in the Brazilian Amazon, whose climatic conditions and soil type are conducive to the palm culture named 'dendê', in Portuguese). The reliability of this supply chain was obtained from the logistics and production department considered that the efficiency of physical assets through the nominal values of the process OEE indicator and service level of carriers with which they operate, taking into account the distances (the production is more than 3000 km to the consumer markets) and the failure rate charged. Values for use mainly in harvesting palm takes into account productivity in historical data from 2007 to 2013.

There is a high reliability in the process of crude oil removal, refining and processing, with the reliability determined in 95% (ratio between OEE and the load used), arising from the maximum use of 70% of the industrial load, for an average efficiency in resource utilization (OEE) established at 68.25%. However, the extraction presents lower reliability, as it has a low level of mechanization, reaching 80%, and 3 sources (74% for extraction 1; 69% for extraction 2, and 80% for extraction 3) are operated to reduce the risks. It was determined by the industrial strategy that the nominal demand must be distributed respecting the balance that varies from 25 to 40% for the three sources of extraction.

There are three distributors, with demands equally divided, that perform operations under the OEE estimated at 90% for each, whose downstream transport has a 99% reliability (close to consumer markets) and the upstream 95% (away from the industrial base). For the customers of chocolates, there is an operation of three carriers, because of the accuracy regarding the schedule and the compliance of these customers' request, while for "cookie" and "ice cream" there is an operation of two designated carriers. The shipping balance for the carriers must respect the balance of 30% to 60%. The reliability of 90% for the transport of the finished product for other customers is also considered. The complexity of the operated packaged load reduces the reliability of the transport, as well as the high distances, providing a reliability of 90% for the transport of packages and 98% for their production. The same configuration is given for additives I and II, and whey. Moreover, we arbitrated the reliability of 95% for the transport of products ranging from the extraction to the production of oils, fats and margarines.

Figure 6:Theoretical model of the simulated supply chain



Source: Information collected in organization (2014)

Legend: Extraction; Crude oil; Refined oil; Customer – cosmetics/bakery/chocolate/cookie/ice cream; Oils and fats; Distributor; Additives; Packages; Whey; Caption: Transport; Operation; Customer.

5.2 Mathematical modeling

Taking into consideration the characteristics of the productive chain and its restrictions, we could model the chain as a network flow problem. We estimated the demand calculating the production needed at the beginning of the chain (extraction) for the following annual product demands: (A) 300 ton of palm oil for baking, (B) 150 ton for ice-cream industries, (C) 200 ton for chocolate industries, (D) 200 ton for the production of cookies and (E) 250 ton for the cosmetics industry.

The variables and coefficients of the problem (Table 2) allow us to define and specify the basis for the mathematical modeling.

Table 2:Composition of the variables and coefficients

NAME	TYPE	REPRESENTATION
Bakery Demand Ice Cream Demand Chocolate Demand Cookie Demand Cosmetics Demand	Variables	D_1 D_2 D_3 D_4 D_5
Amt. from distributor 1 Amt. from distributor 2 Amt. from distributor 3	Variables	X_1 X_2 X_3
Amt. produced in processing Equivalent amt. of refined oil Equivalent amt. of crude oil	Variables	X_4 X_5 X_6
Amt. of palm extracted Amt. of whey Amt. of packages Amt. of additives I Amt. of additives II	Variables	$Y_i \quad \forall\ i = 1A, 1B, 1C$ Y_2 Y_3 Y_4 Y_5
Reliability of the transport Reliability of the production Reliability of the distributor	Coefficients	$R_{Ti} \quad \forall\ i = 1,2,\ldots,23$ $R_{Xj} \quad \forall\ j = 1,2,\ldots,6$ $R_{Yk} \quad \forall\ k = 1,2,3$

Source: Own elaboration (2014).

In Table 3 we show the objective function and the constraint set associated to the problem:

Table 3:Mathematical formulation of the problem of networks

CHARACTERISTIC	FORMULATION	REPRESENTATION
Objective Function	$MAX\ \varphi = \sum_{i=1}^{5} D_i \quad \forall \quad i = 1,2,\ldots,5$	The meeting of the final demand must be maximized
Set of restrictions 1	$D_1 \leq 300 \quad D_2 \leq 150 \quad D_3 \leq 200$ $D_4 \leq 200 \quad D_5 \leq 250$	The market does not absorb the extra production specified. Therefore the quantity produced must be less than or equal to expected demand.
Set of restrictions 2	$R_{T21}.R_{X1}.X_1 + R_{T22}.R_{X2}.X_2 + R_{T23}.R_{X3}.X_3 = D_1$ $X_1.R_{T11} + X_2.R_{T12} + X_3.R_{T13} + D_{2A}.R_{T14} + D_{2B}.R_{T15} + D_{2C}.R_{T6} + D_{3A}.R_{T17} + D_{3B}.R_{T18} + D_{4A}.R_{T19} + D_{4B}.R_{T20} = X_5$ $Y_2.R_{T8} = X_5$ $Y_3.R_{T9} = X_5$ $Y_4.R_{T10} = X_5$ $X_4.R_{T6}.R_{Y4} = D_5$ $Y_1.R_{T5} = X_4$ $X_6.R_{T4}.R_{X6} = X_5$ $Y_{1A}.R_{Y1A}.R_{T1} + Y_{1B}.R_{Y1B}.R_{T2} + Y_{1C}.R_{Y1C}.R_{T3} = X_6$	Refers to equations of equivalence of the networks amount. This set of constraints we seek to balance the network to ensure that there is no loss of relative amounts in the middle of the chain.

Set of restrictions 3	$D_{2A}+D_{2B}+D_{2C}=D_2$ $0,3D_2 \leq D_{2A,2B,2C} \leq 0,6D_2$ $D_{3A}+D_{3B}=D_3$ $0,3D_3 \leq D_{3A,3B} \leq 0,6D_3$ $D_{4A}+D_{4B}=D_4$ $0,4D_4 \leq D_{4A,4B} \leq 0,6D_4$ $0,25X_6 \leq Y_{1A,1B,1C} \leq 0,4X_6$	Refers to the balance constraints intrinsic to the studied chain
Set of restrictions 4	$D_i, X_i, Y_j \geq 0$	Refers to the non-negativity constraints of variables

Source: Own elaboration (2014).

VI. RESULTS AND DISCUSSIONS

4.1 Bullwhip effect and reliability generated in the chain model.

The optimal result obtained from the mathematical model of the supply chain studied points to a bullwhip effect of **104.22%** at the end of the palm extraction chain. In nominal terms, the production, which should be 1,100 ton, was 2246.38 (Table 4).

Table 4:Bullwhip effect at the initial end of the chain

NAME	INDEX	VALUE (T)
AMT. DISTRIBUTOR 1	X1	103.071532
AMT. DISTRIBUTOR 2	X2	103.071532
AMT. DISTRIBUTOR 3	X3	103.071532
AMT. PRODUCED IN PROCESSING	X4	1258.14378
EQUIVALENT AMT. OF REFINED OIL	X5	1494.98589
EQUIVALENT AMT. OF CRUDE OIL	X6	1656.49406
AMT. OF PALM EXTRACTED 1A	Y1A	788.806696
AMT. OF PALM EXTRACTED 1B	Y1B	612.42756
AMT. OF PALM EXTRACTED 1C	Y1C	845.15003
AMT. OF WHEY	Y2	1397.93754
AMT. OF PACKAGES	Y3	1397.93754
AMT. OF ADDITIVES I	Y4	1661.09543
AMT. OF ADDITIVES II	Y5	1397.93754
BAKERY DEMAND	D1	300
ICE CREAM DEMAND	D2	150
CHOCOLATE DEMAND	D3	200
COOKIE DEMAND	D4	200
COSMETICS DEMAND	D5	250
TOTAL AMT. OF DEMAND (tonnes)		1100
AMT. PRODUCED (tonnes)		2246.38429
BULLWHIP EFFECT AT THE END OF THE CHAIN		104.22%

This surplus amount, 1146.48 TON, is distributed in the chain in the form of finished goods inventory, resulting in cost and hence less competitive. Although not the focus of the research is worth mentioning that this inventory loss is incidental, since the location of production is distant from the extraction and marketing (customers).

After calculation of bullwhip we performed the procedure to obtain the overall reliability of the chain through the reliability block diagram (RBD) technique that calculated the relations of probability in series (dash) and parallel (two slashes), as well as the conditional probabilities to obtain the reliabilities for each family of customers (Figure 5).

Table 5:Reliability relations in the chain

RELATIONSHIP [parallel (//) or series (-)]	RELIABILITY	Index
Rx4-Rt1	73.500%	
Rx5-Rt2	67.620%	
Rx6-Rt3	78.400%	
(Rx4-Rt1)//(Rx5-Rt2)//(Rx6-Rt3)	98.147%	A
Rx3-Rt4	90.250%	
A-(Rx3-Rt4)-Rt5-Rt6	**71.748%**	B
Rt6//Rt7	99.500%	C
B-C	79.321%	
Rt8//Rt9//Rt10	99.900%	D
(BB-C)-D	79.242%	E
Rt11-Rd1-Rt21	92.169%	
Rt12-Rd2-Rt22	92.169%	
Rt13-Rd3-Rt23	92.169%	
(Rt11-Rd1-Rt21)//(Rt12-Rd2-Rt22)//(Rt13-Rd3-Rt23)	99.952%	F
E-F	**79.204%**	
E-(Rt14//Rt15//Rt16)	**79.232%**	G
E-(Rt17//Rt18)	**79.044%**	
E-(Rt19//Rt20)	**79.044%**	

Source: Own elaboration (2014)

We calculated the overall reliability for each family of customers to assess the overall reliability of the chain. We obtained the weighted average from the representativeness of each type of customer and arrived at a **reliability of 77.11%** (Table 6).

Table 6:Overall reliability of the chain

CUSTOMERS	RELIABILITY	REPRESENTATIVENESS
COSMETICS	71.748%	27.27%
BAKERY	79.204%	13.64%
ICE CREAM	79.232%	18.18%
CHOCOLATE	79.044%	18.18%
COOKIES	79.044%	22.73%
RELIABILITY OF THE CHAIN		77.11%

Source: Own elaboration (2014)

Despite having a smaller amount of links in the supply chain, which suggests a greater global reliability, the results for the customers of the cosmetics industry contradict this premise. A big impact factor for the lower reliability attested is the existence of only one supplier for the end customer, as well as the existence of channels in series, while the other ones, with greater complexity, have several channels in parallel in the chain in order to increase reliability (Table 5).

The diversification in the chain, to reduce the risks of the channels operation, was well developed by the RBD model, as operations in parallel tend to increase the overall reliability of the segment. Because of the characteristic of the studied supply chain, the production stages are centered, except for the initial phase of extraction. This does not allow the increase in reliability because of the several sources of production.

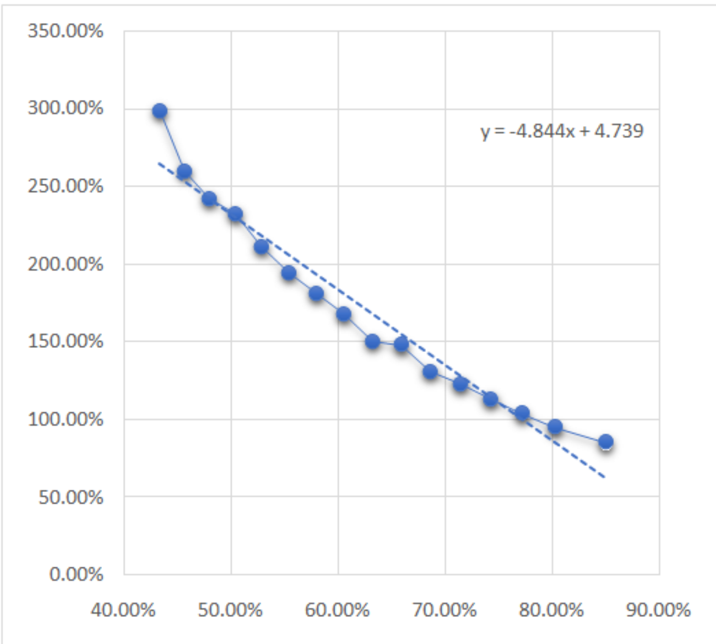
The inclusion of the distributors represents another degree of complexity in the supply field for bakery, compared to "ice cream", "chocolate" and "cookies", and did not represent a major impact to the chain reliability. We can explain by the existence of several channels of distribution and transport involved.

a. Relation between the overall reliability of a chain and the generation of the bullwhip effect.

The main goal of this work was to assess the possible existence of a causal relationship between the generation of the bullwhip effect and the reliability along a supply chain. For this purpose, we used the supply chain modeling for palm oil. To verify the relation, we multiplied the values of the reliabilities of the parts of production and transport, in a scale ranging from 0.88 to 1.03, in order to verify what happens with the bullwhip effect and the overall reliability (Figure 7).

Figure 7:Verification of the causal relation between the generation of the bullwhip effect (%) and the reliability in the chain (%)

RELIABILITY OF THE CHAIN	BULLWHIP EFFECT
43.290%	299.050%
45.580%	260.070%
47.930%	242.280%
50.330%	232.558%
52.790%	211.900%
55.310%	195.160%
57.870%	181.300%
60.480%	168.250%
63.150%	150.960%
65.860%	148.380%
68.610%	131.460%
71.410%	123.150%
74.240%	113.420%
77.110%	104.220%
80.200%	95.520%
84.960%	85.290%



Source: Own elaboration (2014)

The results obtained with the variation of reliabilities in parts of the chain point to the existence of an inversely proportional causal relation, which the higher the global reliability, the lower the generation of the bullwhip effect. Besides the clear relationship shown in the graph, the correlation obtained was **-0.9765**, confirming this relation.

Reliability can be associated with the OEE, as it addresses the **availability**, which relates to the extension and to the meeting of deadlines, the **performance**, where the process optimization stands out, and the **quality**, with attention to rework and production wastes. The importance of the result obtained is in the verification that the uncertainty and deficiency in the flow of information on the demand is not the only factor that influences the generation of the bullwhip effect. The production flow is also strongly influenced by the reliability of the stages. This reliability is related to the accuracy of production methods, quality and compliance with deadlines, an aspect of huge importance in transport logistics.

VII. FINAL REMARKS

The results point to a consistent and inverse correlation between the impact of the operational efficiency considering the supply chain players and the generation of the bullwhip effect. This suggests that there are causes beyond the demand uncertainty and in the relationship level, represented by information flow along the chain.

Measuring and modeling the bullwhip effect is a difficult task. Anyway, the use of network problem model proved to be useful to expose the studied chain specific restrictions and peculiarities with relative simplicity it also worked to compute the bullwhip effect assuming the distortions of the demands that are produced upstream and what is requested, and the availability to the client.

We also highlight the use of the reliability block diagram, which is a method derived from the reliability engineering of industrial systems, such as the available methodology to measure the overall operational efficiency from the defined parameterization of the chain agents. This method meets the practices in the supply chain management: the more diversified the distribution channels is, the greater is the margin of confidence (items in parallel), and the diversification of suppliers is important to reduce the risks (items in parallel). On the other hand, the more complex and full of stages and links, the more vulnerable the chain tends to be (items in series).

It is worth pointing out that this is an introductory study about the subject. For future studies, we suggest the application of the methodology in other types of supply chains to verify the methodological consistency and assure if the specific aspects inherent to other types of chain influence in the obtained results. In addition, we also suggest the comparison of the impact of demand uncertainty, comparing the operational efficiency in the generation of the bullwhip effect.

The operational reliability parameterization, as the translation of the operational efficiency, is still a challenge. In this study, we took into account the OEE indicator and the capacity utilization to measure reliability. However, studies in this direction are important to measure the reliability of the logistics operations, whose transport relates mainly to the deliveries on time and the conformity of the goods delivered.

The OEE as a metric for parameterization of operational reliability we chose to address the intrinsic losses ace operations. However, you can use other ways to measure the reliability of each member of the chain. It is usual to measure the reliability index for transport delays and / or damage in shipping. One can still measure through failure rate or business relationships with suppliers, otherwise, bolder; we measured from the bargaining power of suppliers in a negotiation. All this is to confirm that the parameterization may have different approaches depending on the context in which it is inserted.

Finally, we emphasize that the main contribution of the research mainly focuses on methodology, using techniques and procedures related to the management of industrial maintenance, RBD, as a method to calculate the overall reliability in the same way that modeling on a networks problem found to be useful to give the whip end with distortion on demand ends of the chain (original supplier and end user).

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Ailson R. S. Picanço, et. al. "What are the main differences and similarities between TPM and RCM?." *International Journal of Engineering Research and Applications (IJERA*), vol.12 (07), 2022, pp 92-107.