國立交通大學

工業工程與管理學系

碩士論文

比較拉式與推式系統應付供應鏈瓦解的效應

Comparing the effectiveness of Push and Pull System in handling Disruptions in a Supply Chain

Student: Iveth Anais Arce Serrano

研 究 生：艾薇思

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中華民國一百零三年六月

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摘要

大自然與人為的災害可能在任何時候發生導致供應鏈瓦解，雖然知道有潛在風險，許多公司並沒準備好如何應變供應鏈短暫的瓦解，也沒有意圖改善供應鏈在災害發生時可以靈活應對。

本研究目的即是透過 Avraham Y. Goldratt Institute 研發的軟體來模擬分別在供應鏈上使用推式和拉式系統的表現，並證實了運用拉式系統，公司可以較有效處理在短時間內供應鏈的瓦解.

關鍵字： 供應鏈, 拉式與推式系統, 彈性

Comparing the effectiveness of Push and Pull System in handling Disruptions in a Supply Chain

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Abstract

Natural or man-made disasters can occur at any moment results in supply chain disruption. Although companies known the potential risks their business are exposed, many of them are not prepared to respond to demand during a disruption in their supply chain, neither intend to invest in create or redesign their supply chain to be resilient against those events.

The purpose of this research is by using the simulation software developed by Avraham Y. Goldratt Institute will compare the performance of a pull and push supply chain system design, also confirm the assumption that with a pull system a company can better handle a short time disruption of the supply chain.

Keywords: Supply chain, Push and Pull System, Resilience.

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Chapter 1. Introduction

1.1 Background

Frequently supply chains are exposed to several risks that cause disruptions. A Supply Chain Disruption is defined as an unplanned event that might affect the normal, expected flow of materials, information and components (Skipper & Hanna, 2009; Son & Orchard, 2013). Some sources of disruptions are natural disaster, plant shutdowns, port lockouts, political and labor unrest, IT system failure, industrial accidents, social-economic-political instability, war, terrorism among others (Son, 2013; Zegordi and Davarzani, 2012).

It's known these events have low probability of occurrence, but can produce large losses. The consequences of disruptions on the companies can be losses of revenue, market share and consumer trust; recovery cost, bankruptcy, delay of material and information. (Zegordi & Davarzani, 2012).

In recent years many types of unpredictable natural disasters occurred. For example, on September 1999 Taiwan Earthquake, 2004 Tsunami in South East Asia, the hurricanes Katrina and Rita in 2005, Haiti earthquake in 2010, April 2010 the eruption of a volcano in Iceland, March 2011 the Tohoku earthquake resulting tsunami in Japan and the severe flooding experienced in Thailand between June and December 2011. The 9/11 terrorisms attacks in 2001 was a manmade disaster who also affects in large scale the supply chains.

The earthquake and the following tsunami occurred in Japan on 2011 caused a disruption on the upstream and downstream global supply chain because Japan is a major supplier and also produce many end products in different industries as manufacturing and chemical industries. The economic damages were 210 billion

United States Dollars (USD), automobile production declined 47.7 % and electrical component production 8.25%. Not even affect Japan, but also the consequences in the automobile production and electrical components were reflected among other countries in the region (Thailand, Philippines, Indonesia and Malaysia). Figure 1 shows a graphic of the impact spill over from Japan earthquake. (Ye & Abe, 2012)

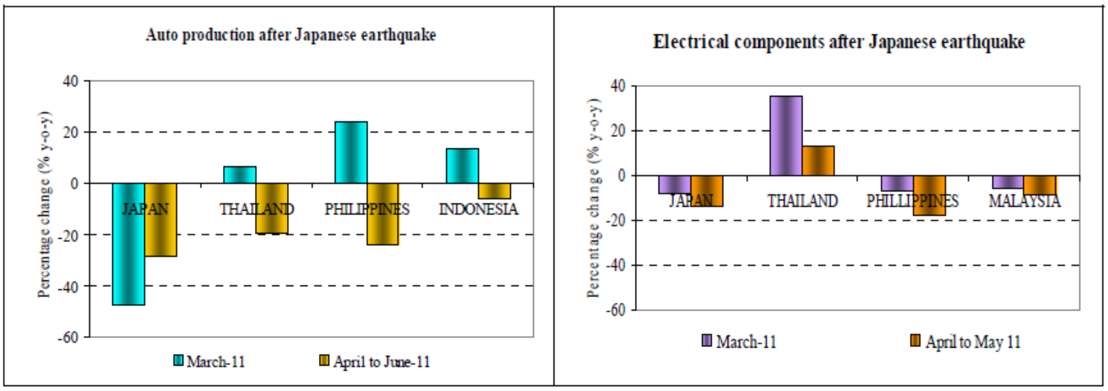

Figure 1. Disaster impact spill-over from Japan earthquake
Source: Ye & Abe, 2012

As presented in the example above, the consequences of disruptions are expanded along the whole supply chain; for this reason it is necessary be prepared to face the impact of those events. In addition, due to the increment of disruptions around the world, in the recent years the concept resilience have been popular, resilience is understand as the ability of a material to return to its original state after an alteration or deformation (Stewart, Kolluru, & Smith, 2009); resilience is not only the ability to back to the original condition, but also is the ability to move to a new and more desirable state after being disturbed (Christopher & Peck, 2004).

On the other hand, some authors have utilized the term resilience in the supply chain context. For example, (Falasca, Zobel, & Cook, 2008) described supply chain resilience as the ability of a supply chain system to reduce the probabilities of a disruption, the consequences of those disruptions once they occur and the time to recover normal performance; (Harrington, 2014) define it as the ability of reduce and recovery from risks, additionally anticipates, rapidly adjusts and take advantage of unanticipated supply chain events. However, in this study the concept of supply chain resilience will be used as the ability of a supply chain system to reduce the recovery time and the effects resulting from an unexpected incident.

As mentioned before, natural disasters can occur at any moment result in economical and physical damages to persons and companies. Although companies known the potential risks their business are exposed, many of them are not prepared to respond to demand during a disruption in their supply chain, neither intend to invest in create or redesign their supply chain to be resilient against those events. Previous research has been studied disruptions in supply chain and suggests strategies to mitigate their effects and improve the resilience on the supply chain.

To analyze the resilience capacity of the presented distribution supply chain it will apply the push and pull systems. In general, push is described as a speculative process because anticipate the customers' orders based on long term forecast and the pull process is defined as the reactive process based on customer orders (Chopra & Meindl, 2007). The purpose of a push based supply chain is take advantage of economies of scale in manufacturing and transportation, while a pull based supply chain seeks to decrease lead time, system inventory, system variability and increase customer service levels (Ahn & Kaminsky, 2005).

For research purposes a virtual supply chain will be simulated in the Distribution Software developed by Avraham Y. Goldratt Institute, in which a disruption will take place in the production plant of a company that may be located in a city. This company has regional warehouses situated in different cities that are responsible for supplying the retailers on each area. The company simulated manufactures six different products. Through running different tests the performance of push and pull supply chain systems will be observed. Results are going to be analyzed and it will help to conclude which of the systems is the most qualified to satisfy the customers demand when disruption occurs.

1.2 Purpose of Study

In real life, also in semiconductor manufacturing companies, in each stages of the supply chain system it has an inventory of products to respond to fluctuations on customers' demands in a short period. The level of inventory that holds each stage depends of the way that the supply chain system is set. This study seeks to support the assumption that the whole supply chain system keeps enough inventories to face a disruption during a short period, and by running our supply chain by pull system it is possible to meet the demand with the existing inventory and the time to recover the normal inventory levels will be less compared with a supply chain push system.

In general, push is described as a speculative process because anticipate the customers' orders based on long term forecast and the pull process is defined as the reactive process based on customer orders (Chopra & Meindl, 2007). The purpose of a push based supply chain is take advantage of economies of scale in manufacturing and transportation, while a pull based supply chain seeks to decrease lead time, system inventory, system variability and increase customer service levels (Ahn & Kaminsky, 2005).

To analyze the performance of both systems under a disturbance, this research employed the Distribution Simulator Software developed by Avraham Y. Goldratt Institute, which attempts to create a disruption in the manufacturing plant of a company which interrupts the normal flow of finished goods through the supply chain. Running the simulator will be compared the behavior of the supply chain during the disruption and the following time using push-based and pull-based supply chains systems, focusing in the distribution between manufacturing plant, regional warehouses and retailers in order to meet the customers demand during the disruption up to restored to a normal state. Additionally, compare the recovery time and economic consequences in each situation. The results will show if the assumption presented about the pull based supply chain system is the best option of a supply chain design in order to handle supply side disruptions.

1.3 Thesis Structure

This research is organized in 5 chapters. Chapter 1 includes background with the description of the system and also the purpose of this project; the Literature review about disruptions and Supply Chain Resilience will be address in Chapter 2. The Chapter 3 presents the decision making scenario where the system and the different scenarios will be described and Chapter 4 shows the results of the experiments from the distribution simulator. The final chapter, conclude with the knowledge acquire after the research and ultimately the direction for future researches.

Chapter 2. Literature Review

2.1 Disruption-Resilience Studies

Due to on recent years the probabilities of disruptions has been increase and around the world have occurred many events who interrupt the normal flow of products, information and people; researches has been studying the disruption in the supply chain. The way they focus their studies is developing strategies to improve the resilience on the supply chain while is faced a disruption. Some of the researches which proposed different strategies are summary in Table 1.

Table 1. Disruption and Resilience Studies

Paper	Author	Objective	Methodology
Financial performance of supply chains after disruptions: an event study	Papadakis, I. S. (2006)	Analyze financial effects after disruption (increment on component prices)	Comparing MTO and MTF business strategies
Robust strategies for mitigating supply chain disruptions	Tang, C. (2006)	Use robust strategies to help to reduce cost and improve customer satisfaction under normal circumstances. Also enable firm to sustain operations during and after major disruptions.	Implementing Robust strategies: Postponement, strategic stock, flexible supply base, make and buy, economic supply incentives, flexible transportation, revenue management, dynamic assortment planning and silent product rollover.
A decision support framework to asses supply chain resilience	Falasca, M.; Zobel, C. W. and Cook, D. (2008)	Develop a model can help to quantify resilience in the supply chain. Using Determinants of SCR: Density, complexity and node critically	Decision support Framework using Determinants of SCR: Density, complexity and node critically
Supply Chain redesign for resilience using simulation	Carvalho, et al. (2012)	Use simulation as a tool to support the decision making process in SC design to create more resilient SC. Strategies: flexibility and redundancy.	SC resilience design strategies: flexibility and redundancy
Effectiveness of policies for mitigating supply disruptions	Son, K. Y. and Orchard, R. K. (2013)	Analyze effectiveness of two inventory based policies for mitigating the impact of Supply Disruptions	Inventory based policies: strategic inventory reserve (R-policy) vs larger orders (Q-policy).

Source: Made by the author

To analyze disruptions in the supply chain, researchers focus in different views of point, for example, (Papadakis, 2006) presents a real situation, a case study of the disruption caused by an earthquake in Taiwan in 1999 and the impact in computer industry which is recognized because release new products very often. The PC manufacturer companies mentioned in the study represents two different production policies: Dell and Gateway with a make to order (MTO) business strategy, while Compaq, Hewlett Packard and IBM focus on the traditional make to forecast (MTF) system. The differences between both policies are that in a MTF strategy the company holds inventory of end products for a long period and MTO strategy has the advantage of introduce new products without having inventory of previous final goods and also produce based on customer order. The objective of this research is analyzing the financial effects after a disruption based in the increment in pc component´s prices. With the comparisons of the performance based on revenue, earnings and earnings over revenue were concluded that the price of components in the PC market is more vulnerable during disruptions under the business strategy MTO (make to order). However, due to the nature of the disruption (an earthquake) the MTO companies do not need to change their business structure to get more profit during disruptions; by implementing a risk management policy they can face this kind of events.

Also has been conducted researches where was suggested strategies to enhance the resilience capability in supply chain during disruptions. The contribution made by (Tang, 2006), was to recommend nine robust strategies to mitigate disruptions and increase the resilience in a supply chain. The proposed robust strategies are: Postponement, strategic stock, flexible supply base, make and buy, economic supply incentives, flexible transportation, revenue management, dynamic assortment planning and silent product rollover. To achieve resilience, these strategies will focus on increase product flexibility and availability, supply flexibility, transportation flexibility, control product demand and control of product exposure to customers. The advantage to apply these strategies are that will reduce operations costs and improve customer satisfaction in normal circumstances, additionally under disruptions events, will help to handle consequences during the disruption and whereas back to normal performance. At the time of implement these strategies is important analyze the benefits resulting from each strategy, because if the cost on implementation vs benefits is too high, is not worth it; moreover, strategies can also not fit with companies business strategies. Another challenge is that the strategies need to be implemented in a proactively manner, that means before the disruption occurs.

The actions to improve resilience in a supply chain can be implemented before, during or after disruptions, in their study (Falasca et al., 2008), proposed a simulation based framework which is a tool which will help to improve the resilience capacity during the design period of a supply chain. This model includes three determinants of supply chain: supply chain density who refers to the quantity and geographical spacing of nodes within a supply chain; Supply chain complexity who is the relation between number of nodes and interconnection between them and the third determinant the node criticality is the relative importance of a given node within a supply chain. The objective of this study is reducing the impacts and the recovery time from a disruption through increasing the performance of the system by the 3 determinants mention above. By simulation using the software platform Arena and Visual Basic for Application (VBA) is analyzed the future consequences on the recovery time of the system and also cost-benefit of each supply chain design.

While (Carvalho, Barroso, Machado, Azevedo, & Cruz-Machado, 2012) use simulation tool to support decision making process in redesign the Portuguese Automotive supply chain in order to improve resilience to a disturbance. The disturbance in this system affects the transportation of material between two SC entities. Through creating 6 different scenarios could compare the performance of the supply chain under redundancy and flexibility strategies. Redundancy capacity means add a buffer stock to be used during shortage time caused by disturbance, whereas flexibility refers to restructuring existing transport. They compare the behavior of the strategies after a disruption based on the lead time ratio and total cost. At the end, they conclude that both strategies are effective in reducing the negative effects of disturbance, but under flexibility strategy the total cost of the supply chain is lower and the lead time ratio is better compared to redundancy strategy.

A recent research conducted by (Son & Orchard, 2013) studied the impact of two inventory policies in order to mitigate the effects of supply disruptions on the supply chain. The policies utilized are R policy, that focus on maintain a strategic inventory reserve (different from safety stock) and the Q policy, which place large orders with the purpose to hold large stocks of inventory and so meet demand when a disruption occurs; to compare the product availability both policies were simulated under different disruption frequency and recovery rates. The results of the research shows that in a single retail- single supplier system with deterministic demand, the inventory reserve policy is more effective to mitigate supply side disruptions in a supply chain.

These authors presented the different strategies can be applied to create a more resilient supply chain. In contrast with previous studies, this research proposes analyze two strategies: pull and push supply chain systems to accomplish a more resilient supply chain and to reduce the impact because of the disruption. Both systems and also the combined push-pull system will be compared during a disruption in the manufacturing plant during a period of 5 weeks without production.

Chapter 3. Decision Making Scenario

3.1 Description of the System

In this research is studied the distribution supply chain of a manufacturing company. The manufacturing plant of this project is composed by one production line, which is design to produce six different products. For this project the supply chain consist in five stages: raw material supplier, the manufacturing plant, regional warehouses, retailers and final consumers or clients. In the Figure 2 is shown the Supply Chain Design of the Company.

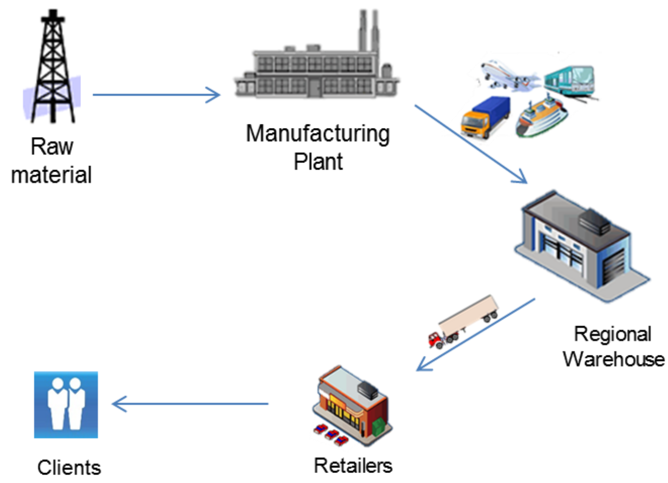

Figure 2. Supply Chain Design of the Company
Source: Made by the author

The plant runs 24 hours per day, 7 days a week giving a weekly available production time of 168 hours. The production rate of the plant is 6 units per hour of production. The production is based on the demand from the regional warehouses; the production manager is the responsible of decide how many units produce from each type of product.

Since the plant does not have storage area to maintain inventory of finished goods, the products are sent to each of the five regional warehouses which are able to stock large inventories of the six products and are responsible to distribute their finished goods in different zones of the country. The level of inventory of each warehouse depends on the average regional weekly demand. Each one is responsible to provide the quantity of products requested from each retailer in a lapse time of one week, while the retailers made their orders based on their average sales to final clients. In this system, each regional warehouse has 4 retailers. Figure 3 shows the system to be analyzed.

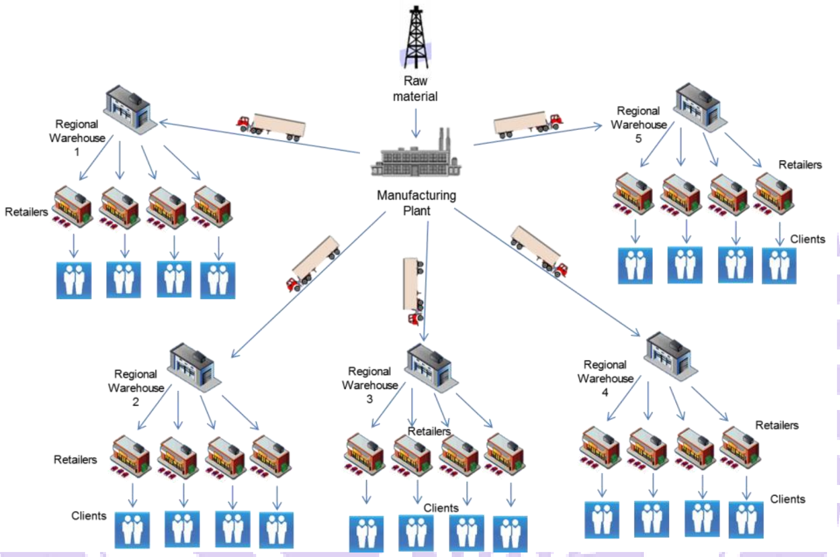

Figure 3. Initial Supply Chain System
Source: Made by the author

The life cycle of all products is 30 weeks; every week retailers revised the age of their products, so the overdue items are shipped back to the manufacturing plant and the company returns the money to them. Also regional warehouses weekly checked their inventory and get rid of expired products. Each product has a setup time of 24 hours and the selling price of finished goods is $35/unit.

The company has a small inventory of raw material to assure the availability of material to start production while received the order. The purchasing is made on batches of 50 but in case the requested quantity is less than 50, only the amount needed is purchased. The cost of raw material is $20/unit. Is assumed the production will not suffer delays due to lack of raw material.

Transfers of finished goods from manufacturing plant to the regional warehouses are performed by the plant. They made daily distribution decisions using as reference transportation batches of 6 units of end product which can be integrated from different products. Each batch has a fixed transfer cost of $5 per day.

As part of the project, is assumed that an unexpected event (natural or manmade) will take place in the area where the manufacturing plant of this company is located, thus resulting in a production breakdown during an unknown lapse of time who depends upon the magnitude of that event. In addition originates a disruption in the supply chain of the system. During this time period, the regional warehouses will keep supplying the retailers' orders until their inventory is finished.

The system to analyze will vary depending on client's behavior and the structure of the system. The following strategies are going to be analyzed: a push based system, pull based system and push-pull based system. Section 3.2 explains the different scenarios to evaluate.

3.2 Decision Making Scenarios

To analyze the performance of the system during disturbances different scenarios will be studied. The purpose is to observe the behavior of supply chain in each scenario when appears a disruption which affect the normal manufacturing process in the production plant. In this situation the inventory maintained in the whole system will be utilized to meet the customers demand until back to the normal state of the system.

Variance in client's behavior and distribution system also are going to be simulated. The plan horizon utilized in all scenarios to calculate average sales to market and inventory levels is a period of 5 weeks. To understand each scenario first is defined their three main characteristics: the System Design, Market and Client's behavior.

The System design refers how compound is the supply chain, if it has a regional warehouse or central warehouse; will face a flat market behavior, and the third characteristic, clients' behavior; where the scenarios will be under normal, good or subordinate clients. Each of the characteristics will be explained in detail.

System Design

In a Regional Warehouse system design, has can be observed in Figure 3 is assumed that the manufacturing facility is small, when products are finished they directly send it in batches of 6 units to the five regional warehouses; each one carry inventory of all products to supply the demand of 4 different retailers and each retailer sell the products to final consumers.

Due to manufacturing plant has no capacity to hold inventory, the decision of distribution from the plant to regional warehouses are made following these priority rules:

a. A region has priority if the inventory level of this particular region goes below the minimum inventory level.
b. Also the shipment for a region has priority if the distance from manufacturing plant is longer.
c. Depends of demand quantity of product (demand order) from each region.

To request the weekly amount of end goods, every five weeks is computed the new average weekly regional demand value; with this value and the current level of inventory in each region, the new weekly demand order is made.

The average weekly regional demand value is calculated at the beginning of each period (as mentioned before, one period is 5 weeks), by using the last period demand value and the average sales to clients of the last 5 weeks in a weight ratio of 2:1.

Using the average weekly demand value, the weekly decision of regional demand will follow these rules:

a. If the current inventory level is lower than 0.66 of the maximum level, the weekly demand will be 1.2 of the average weekly demand value.
b. If the current inventory level more than 1.7 of the maximum level, the weekly demand will be zero.
c. If the current inventory level is more than 1.2 and less than 1.7 of the maximum level, the weekly demand will be 0.75 of the average weekly demand value.

Since regional demands not have set a delivery time, during the period the weekly demands are accumulated.

In the second type of system design, the Central Warehouse, the manufacturing plant has a central warehouse where all the finished products will be storage until it is received weekly demand from regions. Adding the central warehouse in the plant will create a buffer to handle the market fluctuations. With this kind of design the minimum and maximum inventory levels in the regional warehouses will drop. The Figure 4 shows the Central Warehouse System Design.

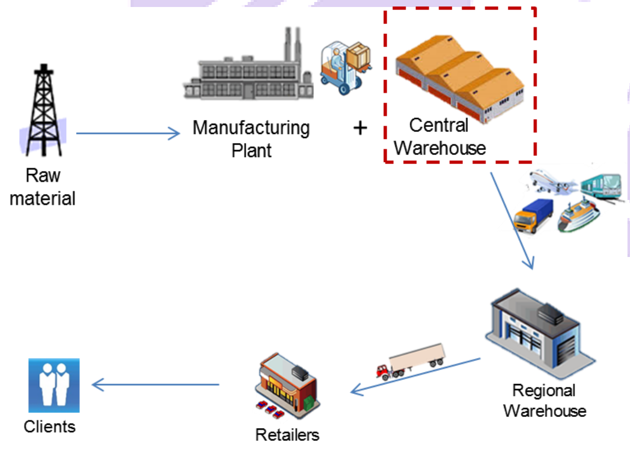

Figure 4. Central Warehouse System Design
Source: Made by the author

The distribution of products from central warehouse to regional warehouses will depends on the current inventory level, which is calculated at the beginning of each period based on the average sales to clients. That means the regional warehouses will not send demand orders every week to the manufacturing plant, instead, the plant will transfer the necessary amount of products to maintain the maximum inventory level.

Market Behavior

The market behavior presented in all scenarios is flat market. In a flat market the levels of sales to clients remains almost the same during all periods (6 units per product per retailer).

The average weekly sales of the system is 6 units per product per retailer, giving a total weekly average sales of 720 units (6 products * 6 units/product * 20 retailer), the region weekly average sales is 144 units (6 products * 6 units/product * 4 retailer) and product weekly average sales 120 units/product (6 units * 20 retailer).

Clients Behavior

In the different situations the system is set also by the clients' behavior. Each one is compound of a set of rules which retailers based their decisions at the moment to send orders to regional warehouses. Those clients will be normal, good or subordinate. Under **normal client's** behavior, retailers support their order decisions on forecast and experience, while their inventory levels are fixed: maximum of 60 units per product (which covers 10 weeks of average sales) and a minimum inventory level of 24 units per product (4 weeks of average sales). In this case, for the regional warehouse the minimum inventory level is 96 units, which represents the minimum level of one retailer 24 units multiplied by 4 retailers in each region, and a maximum inventory of 240 units/product (60 units *4retailers).

Retailers send orders to regional warehouses each week and this orders need to be fulfilled within one week. To calculate the weekly orders, first for a period of 5 weeks the retailers calculate the average sales value. This average sale value is calculated by old average value and the sales of the previous 5 weeks with a weight ratio of 2:1. After calculate this value, retailers make their weekly orders decisions considering the following situations:

a) The new order quantity is 0, if the current inventory level is more than 1.7 of the maximum inventory level.
b) If the current inventory level is more than 1.2 of the max level, the new order value will be 75% of the average sales values.
c) If the sum of the current inventory level, open orders and one fixed order is less than minimum inventory level, a special order is issued to return to the minimum level.
d) If the overall inventory is less than 66% of the maximum the order will cover the difference in 2 periods.

For **good clients** the average sales value for each period is calculated from the old average sales value and last plan horizon with a ratio of 5:1. The inventory levels at retailers and regional warehouse represents 6 weeks of average sales. The maximum and minimum inventory levels will change if there a case of missed to market.

For weekly orders the quantity requested is the difference from maximum level of inventory from current inventory and inventory on transit. Also during the week urgent orders are issued because of the following situations:

-The sum of current inventory level and the inventory in transit below the minimum inventory level an urgent order is issued to get back to the minimum level.

-There is a miss to market.

In **subordinate clients'** situation, the average sales to market are calculated in the same way as normal clients, the weight ratio between old average sales value and the last period sales under this behavior is 5:1.

The inventory levels on retailers are calculated based on the average sales, for maximum inventory level is 6 times the averages sales. But the max-min inventory level is not fixed, will vary depends on weekly inventory levels. If more than twice in a period of 5 weeks, the inventory level drops under minimum level, the maximum and minimum levels will increase 10% per time. Instead if inventory level is more than 3 times average sales, the maximum and minimum levels will decrease 5%. The scenario with subordinate clients is based on daily decisions. The orders to regional warehouses are issued daily requesting the amount of product sold the day before.

Based on these 3 main characteristics: system design, market behavior and clients' behavior, the four scenarios will be studied and analyzed are presented in Table 2.

Table 2. System Scenarios

Scenarios	System Design		Market Behavior	Clients' Behavior		
	Regional Warehouse	*Central Warehouse*	*Flat*	*Normal*	*Good*	*Subordinate*
1	X		X	X		
2	X		X		X	
3		X	X	X		
4		X	X			X

Source: Made by the author

The Scenario 1 represented a ***push based*** system because using expected future demand the end products are pushed to regional warehouse and then they are in charge to supply the demand from retailers which is also based on forecast.

Scenario 2 and 3 represents a ***pull-push*** based systems, Scenario 2 still is push system because maintain the regional warehouse system design, but also is pull because under good clients the inventory level are more realistic and just carry 6 weeks of inventory. For scenario #3, the system will be added the central warehouse and the products are storage there before they are sent to regions (pull system); but also is push because of based their order quantity decisions on normal clients' behavior (forecast).

Scenario 4 is the ***pull*** based system because their design includes the central warehouse design which maintain the products in the plant until is requested in each region and also because the decisions are made daily based on previous day consumption.

Chapter 4. Solution Approach

4.1 Overview of methodology

The research seeks to compare Push and Pull system to propose a way to design the supply chain enabling the company to be more capable to handle disruptions in the supply side. Thus, in this study was proposed the analysis of the performance in both systems through employing the AGI Distribution Software developed by Avraham Goldratt Institute. This software is integrated by different simulators; the four simulators utilized in the study have specific parameters that represent all the scenarios explained previously in Chapter 3.

The manufacturing company simulated by the software, where 6 products are produced in one production line and also includes the distribution of those products along the supply chain until the end product is sold to final consumers. AGI Distribution Software through different simulators recreates the scenarios of push and pulls systems which were utilized to analyze the capacity to the supply chain system to overcome a disruption. The decision made by the production manager, or in this case the person who runs the program was the production batch size and selection of which product to produce.

In the software, the supply chain disruption suffer in the manufacturing plant was represented by the absence of production during the first five weeks of the year. The simulations were run during 52 weeks; from week 6 to week 52 was used a fixed production quantity in order to analyze the performance of the system under 4 different scenarios. To generate the data of the scenarios, each simulation was run 30 times.

In the Figure 5 depicts the screen of the software at the beginning of each simulation week. First can be seen the time (month, week, day and time of week) the production decision is made. In this case, is in the first week of the simulation. Then, displays the current amount of cash available ($125,410) to buy more raw materials, cover the weekly fixed expenses to keep producing, daily transportation expenses, weekly interest on inventory and returns.

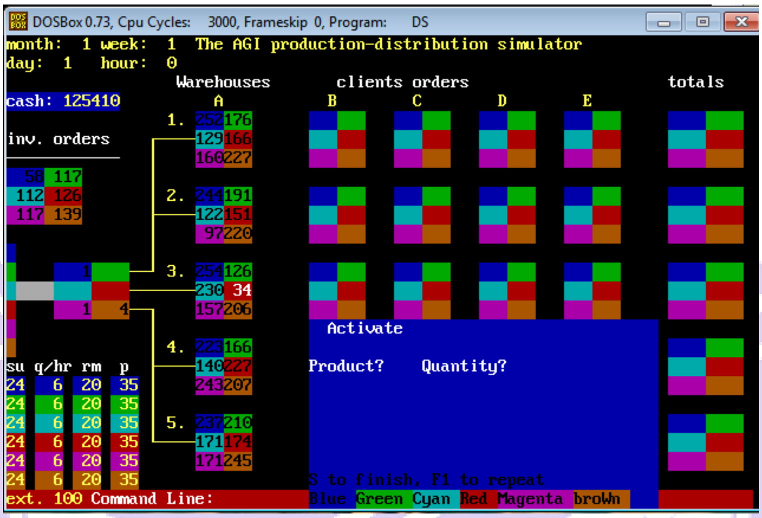

Figure 5. AGI Distribution Simulator Simulation Screen
Source: AGI Distribution Software

Under the weekly cash amount the entitled “Inv. Orders” with six colored boxes presents the weekly demand of regions for each product. The products are represented by one color (blue, green, cyan, red, magenta and brown); below these boxes is located the production line. The quantity of each product observed at the end of the production line is the number of final products that have not been sent to the regional centers yet. In the column A can be observed the current inventory in the five different regional warehouses, the minimum level is calculated depends on the simulation. In the next four columns, B C D and E, which in the software is called as “clients’ orders” for this study refers to the retailer’s orders that will be sending to regional warehouses and the last column “totals” represents the sum of all orders from retailers in each region.

In the bottom left of this screen is also shown information of each product. The column "su" is the setup time (in hours), "q/hr" is the production rate (quantity per hour of production), "rm" defines the price of the raw material and the last column "p" specified the selling price of the end product. All simulations that will be studied have the same values (setup: 24 hours; production rate: 6units/ hour; raw material price: $20/unit and unit selling price: $35), as detailed previously in Chapter 3.

The box with the name "Activate" appears when the line is available to start to produce more products. To select which product and the quantity to produce is necessary write the letter:

- **B** if decided to produce product blue,
- **G** for product green,
- **C** to produce cyan,
- **R** to produce the product red,
- **M** for magenta,
- **W** is the decision is produce brown.

After choose the product, write the quantity of that product to manufacture. It can be choose 1 until 6 products and then press "S" to start the production.

As the screen presented in Figure 5, all the simulations will look in the same manner, but the difference arise in the inventory levels of each stage, the client's demand and if the manufacturing plant can hold or not more than few days of inventory. At first glance, the software does not reveal the current level of inventory for retailers, only the inventory level at manufacturing plant and regional warehouses. In order to observe the current level of inventory at the retailers, is used the command "I"; for displays the maximum and minimum inventory levels at warehouse and also retailers press the command "X", additionally press the command "V" so that the software shows the total inventory on the regions with the units in transit.

Since the plant works 168 hours per week and the average weekly demand is 720 units (6 products * 6 units/product * 20 retailer), to cover the demand under normal production week taking in consideration the setup time (24 hours) and the production rate of 6 products per hour, the weekly schedule produce two products, 360 units each. But this value (360 units/ product) is not fixed; it depends on the production manager. The production quantity of each product was determined to all simulations in this research. Because in this research the first five weeks there is no production due to a natural or manmade disaster, to ensure the rebuilding of inventory to the starting level and also to cover the demand in the coming weeks two actions it could be implemented to enhance the performance of the production plant. The first one was by adding more capacity to the production line and the other one by increasing the production quantity size which increase the percentage of machine utilization by cutting out the setup time.

Because AGI Distribution Simulator used in this project does not offer the facility of make modifications in the templates, to solve this research problem could not be increased the capacity of the production line. For this reason, the first solution was not feasible. But the second one, which means increase the production batch size while eliminating the setup time was implemented since the batch size decision is made by the production manager.

From week 6 when the production restarts until week 52 in all simulations were applied the solution approach of increasing batch size. In this research was chosen the new production batch size of 600 pieces.

The batch size of 600 units was chosen after make a trial with 3 different batch size: 500, 550 and 600 in all simulations. The results of the recovery time by running one time each simulation using different size are presented in Table 3. When was used the batch size of 500 units the recovery time of all simulations except in the system inventory of Scenario 2 takes more than 52 weeks, which is the time period chosen to analyze the different scenarios.

Table 3. Recovery time using different Batch Size

	Recovery Time (weeks)		
Scenario/ Batch Size	**500**	**550**	**600**
#1 Inventory	89	70	58
#1 System Inventory	90	69	53
#2 Inventory	103	92	60
#2 System Inventory	**34**	**27**	**28**
#3 Inventory	64	53	**44**
#3 System Inventory	56	**48**	**40**
#4 Inventory	52	**46**	**41**
#4 System Inventory	53	**40**	**32**

Source: Made by the author

Then, the results using 550 units presents that the recovery time of the system inventory level in Scenario 2, 3 and 4; also the inventory level in Scenario 4 was less than 52 weeks. But the results using the batch size of 600 units give us the recovery time of Scenario 2, 3 and 4 less than 52 weeks, except of the inventory level of Scenario 2.

Additionally of the recovery time using 600 units was less than 52 weeks in most simulations, with a batch size of 600 the cycle time to produce the six products change from 3 weeks (360 units per product) to 4.43 weeks (600 units per product).

The simulator distributes the end products from the manufacturing plant to each regional warehouse and then to retailers automatically, based on the specifications of each scenario. The transportation batch of 6 products could be built with different products.

At the end of each week, the program shows a performance report as Figure 6 display. On the top left of the screen is specified the simulation number, below the month and week (month: 1, week: 2) which represents the report. Then is presented the following data: Missed to clients, missed to market, returns, net profit, return on investment (ROI), cash, starting cash, throughput, inventory, operating expenses, starting inventory, sales to clients, expenses (transport, interest on inventory, returns and fixed), raw material purchase, quantity of pieces produced, quantity of end product sold to clients, quantity of product sold to market, line utilization denoted by % (producing and setting up), current system inventory and starting system inventory.

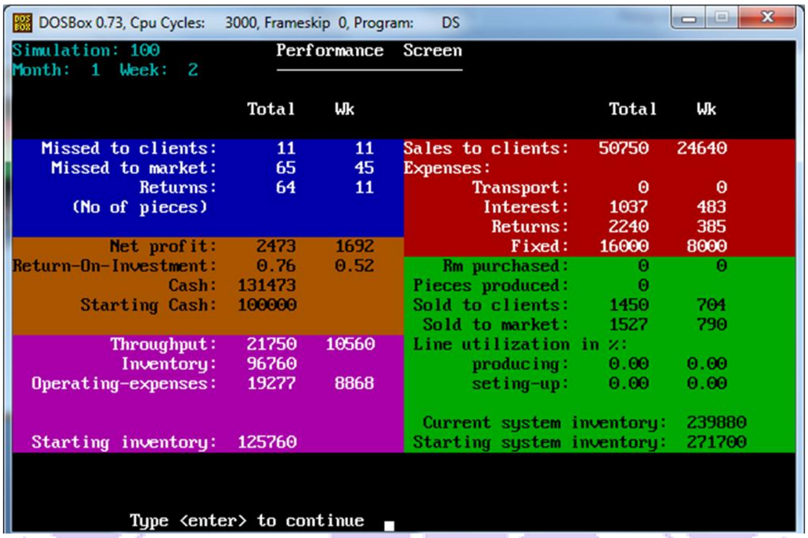

Figure 6. AGI Distribution Simulator weekly performance report
Source: AGI Distribution Software

After 52 weeks, were analyzed the results on the different scenarios using only 7 performance metrics: recovery time, missed to clients, missed to market, returns, net profit, inventory and system inventory, which will be explained in detailed in the section 4.2 Performance Metrics.

As mentioned previously each of the scenarios presented in Chapter 3 are represented by one simulation in the AGI Distribution Simulator. Also each simulation has different starting levels of inventory. In Table 4 is shown each scenario and their corresponding levels of starting inventories, given in amount of pieces and also in the quantity of money that represents.

Table 4. Initial Inventory Level in each Simulation

Scenario	1	2	3	4
System	*Push*	*Push-Pull*	*Pull-Push*	*Pull*
Inventory (pieces)	6288	6669	3849	4203
Total System Inventory (pieces)	13585	10444	11153	6839
Inventory ($)	125760	133380	76980	84060
Total System Inventory ($)	271700	208880	223060	136780

Source: Made by author

The inventory levels in each scenario are different, in case of Scenario 1 who represents a 100% push system, the total system inventory level is 13,585 pieces which means a push based system carry the double of inventory compared with the Scenario 4 which recreate a pull system under normal demand. This huge difference between simulations is due the inventory policy where the different stages (regional warehouse and retailers) should carry 10 weeks of average sales. While Scenario 2 and 3 maintain respectively 23% and 18 % less system inventory than Scenario 1. Because Scenario 2 based their inventory in good clients, the total inventory decreases significantly, but also is noted that even the scenario 2 has more inventory level because also based their levels in forecast.

4.2 Performance Metrics

In order to measure the behavior of the systems, from the Weekly Performance Report which the software displays at the end of a production week, was chosen seven performance metrics to be analyzed in this study. Those performance metrics were:

- **Recovery Time:** is the time when the company recovers the normal performance. The normal performance in this study is defined as retrieve the initial system inventory level of the simulation or scenario (The initial system inventory levels of each scenario are given in Table 4). The inventory and system Inventory information will be used to calculate the recovery time.
- **Missed to Clients**: is the quantity (pieces) of products that the regional warehouse cannot deliver to retailers because there is no product in stock.
- **Missed to Market**: is the amount of products (pieces) of lost sales due to stock out on retailers.
- **Number of Return items**: The products' life cycle is 30 weeks. Overdue products will be shipped back to the plant; these products represent lost to the company because should send a refund to retailers. To reduce the percentage of returned products, there is a rule that first sell the older products, but sometimes the clients require the newest products. This decision is

represented in the software as 90% of sales are oldest products on stock and 10% new products.

- **Company Net Profit**: the net profit is calculated by the throughput minus operating expenses (transport, fixed, returns, and interest on inventory). Is not necessary to calculate this parameter because is provided by the weekly report.
- **Inventory** refers to the current level of inventory at the plant and the regional warehouse.
- **System Inventory** in the amount of products placed in the supply chain which means manufacturing plant warehouse, regional warehouse and retailer inventories.

This data collected from all the simulation runs which were carried 30 times, was compiled in a excel document to be analyzed. Table 5 shows the Excel format utilized to collect weekly performance data on each simulation.

Table 5. Excel format to collect weekly performance data

Company Performance														
Simulation #			Starting system Inventory ($)						Expenses Fixed ($)					
Starting Cash ($)			Starting Inventory ($)											
		Week												
		1	2	3	4	5	6	7	8	9	10	11	12	Total
Missed to clients	Pieces													
Missed to market	Pieces													
Returns	Pieces													
Net profit	$													
Inventory	$													
Current system inventory	$													

Source: Made by author

Chapter 5. Results and Discussion

The research focus on analyze different scenarios when an unplanned event occurs and affects the production planning in a manufacturing company. The simulations were running 30 times each, with a production quantity size of 600 units from week 6 to week 52.

This chapter present result of each scenario based on the seven performance metrics mentioned in the last part of Chapter 4. The totals and weekly results shown in the next figures represent the average results of the 30 runs in each simulation.

Inventory Recovery Time Results

Result of a disruption, no production during week 1 to 5, levels of inventory at each stage will drop. After running the simulations, the data collected in each run will be used to calculate the time when the company recovered their normal performance.

The simulations present two types of inventories, the **total system inventory** which is the sum of the products that are stock in the manufacturing plant, regional warehouse and retailer's warehouse and the **Inventory** which only includes the products that are stock in plant and regional warehouses.

As can be seen in all scenarios (Figure 7 to Figure 14) the inventory and system inventory are significantly decreasing from week 1 to week 5 because those weeks were no production due to an unexpected event, for this reason the current inventory that the company keeps is used to supply the demand during the period without production. After this period each simulation presents a different behavior in the process to recover the starting level of system inventory.

In the case of Scenario 1, the inventory level shown in Figure 7 at the end of the year in average remains under the starting level approximately 10%; while Figure 8 shows that the system inventory level after disruption is increasing as the weeks go by also cannot recover from the disruption within the analysis period, at the end of the that period (52 weeks) the system inventory level has in average 4% less inventory than initially has.

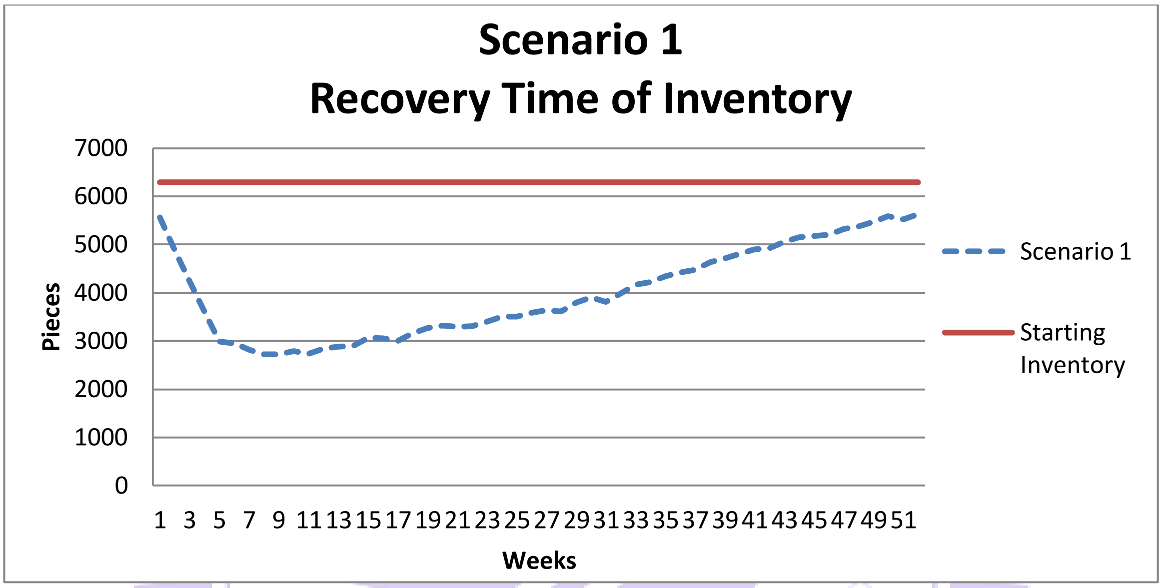

Figure 7. Scenario 1. Inventory Recovery Time
Source: Made by author

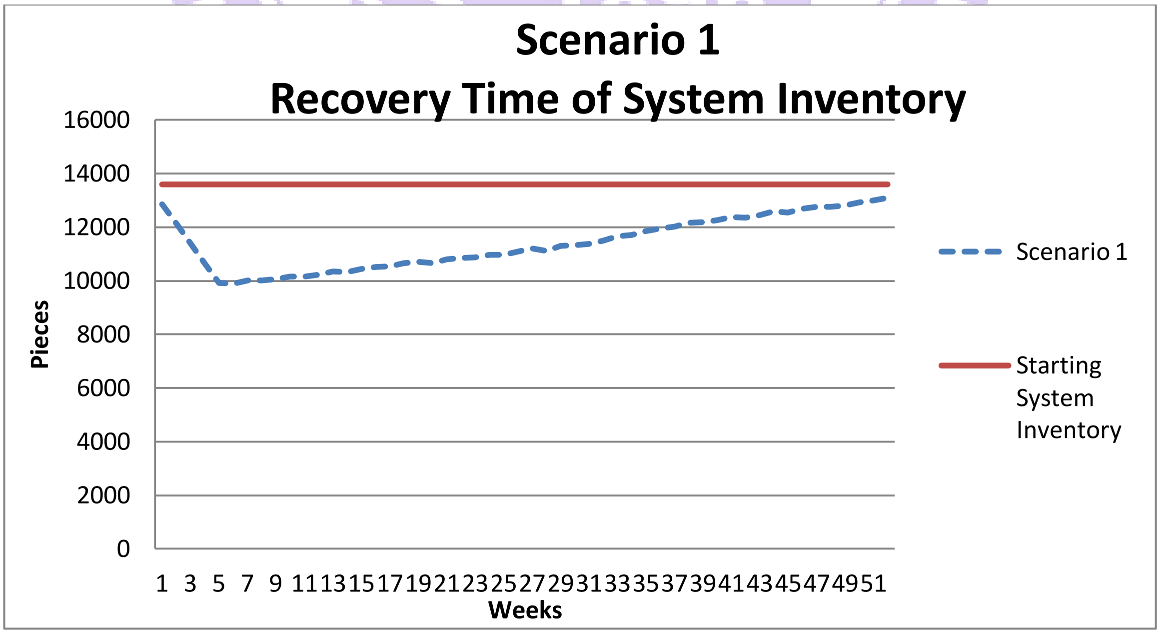

Figure 8. Scenario 1. Recovery Time of System Inventory.
Source: Made by author

Since the research analysis cover until week 52, is not prove in which week the scenario 1 will recover from disruption. But analyzing the data it can be said that around 1 to 3 more weeks (between weeks 53 to 55) could be regaining the system inventory level because in average at the end of week 52, the inventory level is under the starting system inventory level with 497 units.

While in Scenario 1 both inventories levels behave in the same manner, after disruption increase gradually; with the Figure 9 and Figure 10 is observed that in Scenario 2 the inventory and system inventory curves are different. In the Inventory level depict in Figure 9 the curve after disruption continues to decline then remains almost the same level until week 42 and finally increase slightly getting a 57% less inventory than at the beginning of the simulation.

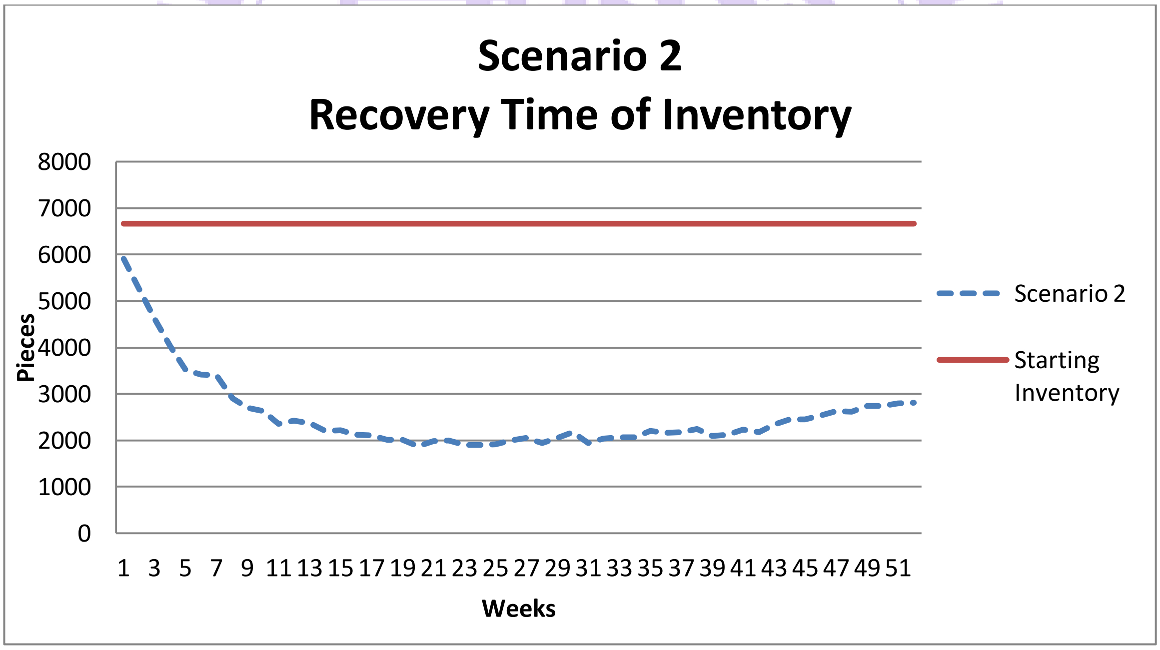

Figure 9. Scenario 2. Inventory Recovery Time
Source: Made by author

Instead, in Figure 10 the system inventory will increase from week 6 reaching up the initial inventory level at week 26. The following weeks the system inventory level completes the period under consideration with an average of 25% more inventory. From the data presented at the end of this Chapter, the average recovery time of the system is 26.93 weeks with a standard deviation of 3.18.

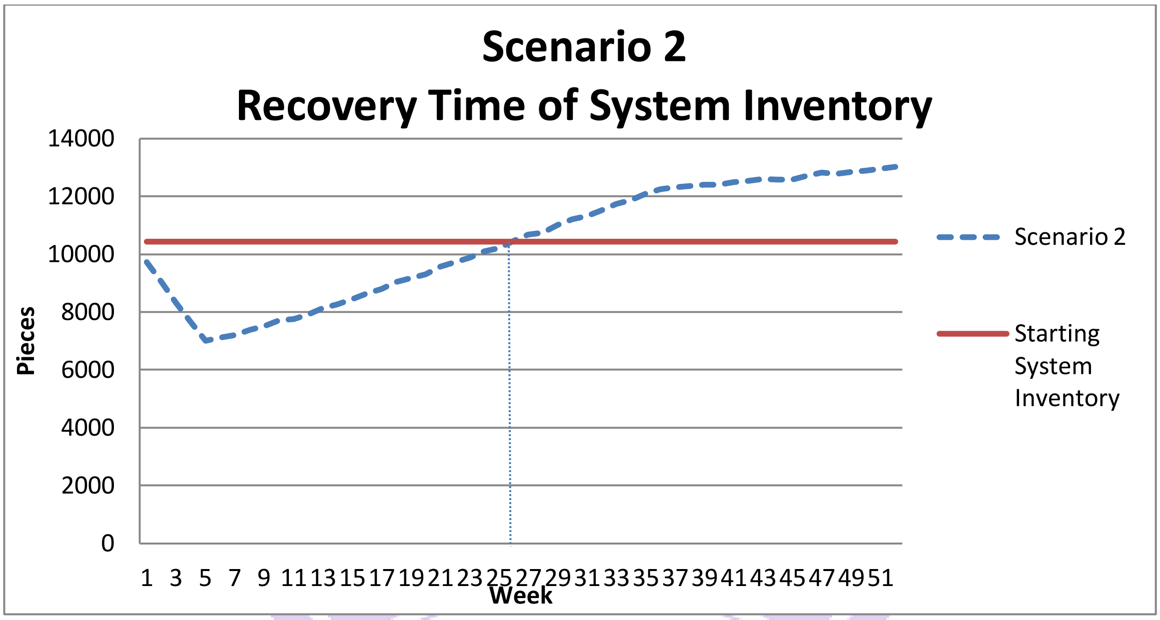

Figure 10. Scenario 2. Recovery Time of System Inventory
Source: Made by author

For Scenario 3 which represents a Push-Pull system, can be observed in Figure 11 in average at week 44 is recovered the initial inventory level. At the end of the year, the inventory level remains 15% over the initial level. Based on Figure 12 the system inventory is recovered in average at week 41, with an 8% more inventory at the end of the simulation run. This push-pull scenario enables recover the initial inventory levels before the analysis period ends. The initial inventory level in Scenario 3 is 3849 units and the system inventory level 11,153 pieces.

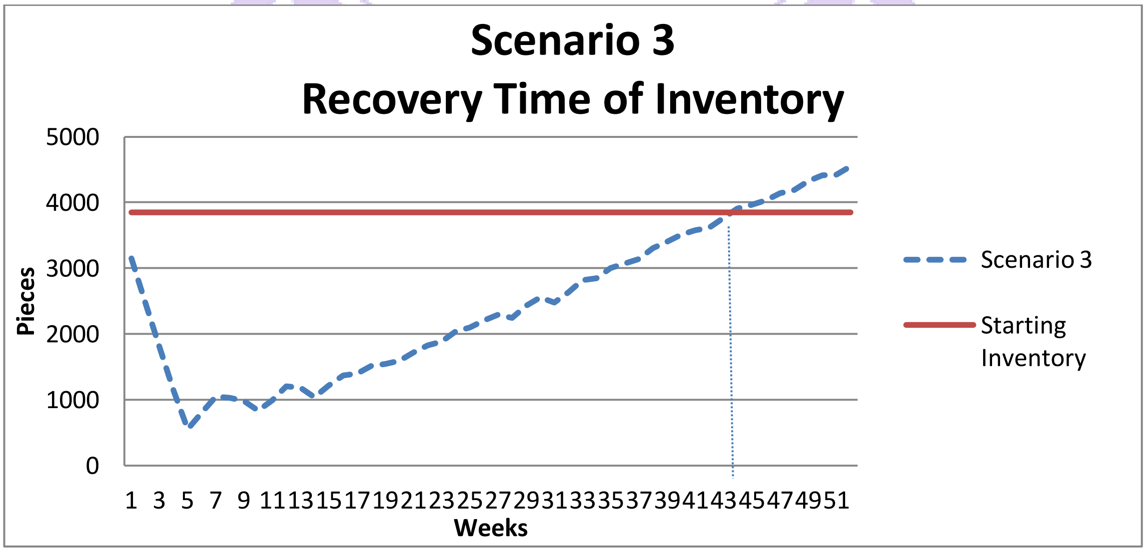

Figure 11. Scenario 3. Inventory Recovery Time
Source: Made by author

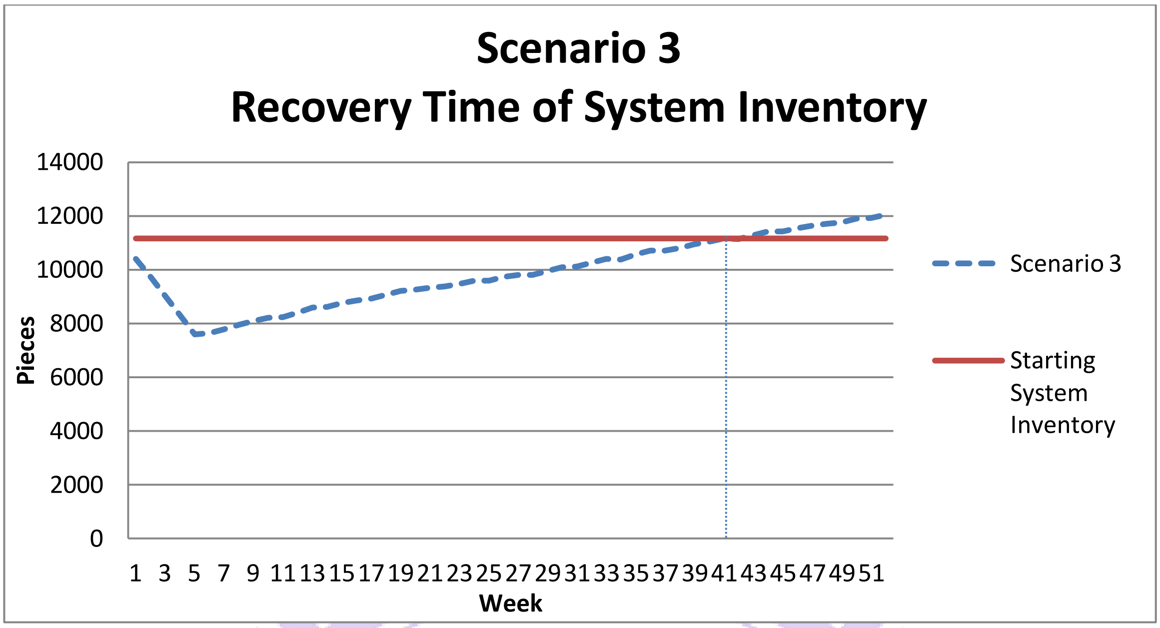

Figure 12. Scenario 3. Recovery Time of System Inventory
Source: Made by author

Figure 13 and Figure 14 presents the behavior of the Pull System in the Scenario 4. As noted in the previous Simulation graphics (Figure 11 and 12 from Scenario 3) both recovery inventory graphics presents the same behavior and also regain their initial inventory levels in a period less than 52 weeks. It can be observed in the following graphs (Figure 13 and 14) that the inventory levels go down until week 5 but on week 6 both will increase until the analysis in complete at week 52. The difference between Figure 13 and 14 remains in the week in which the inventory level equals to the starting level. For Figure 13, on average at week 40 the inventory of Scenario 4 is recovered and based on Figure 14 the system inventory is recovered in average at week 33. At week 52, the inventory level is 23% more than initially and the system inventory level with 24% more.

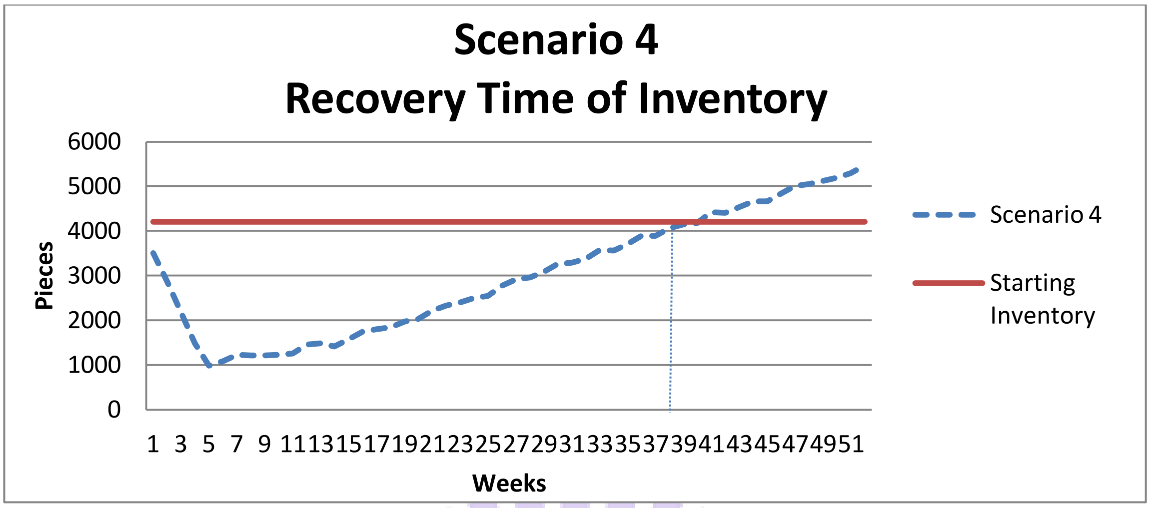

Figure 13. Scenario 4. Inventory Recovery Time
Source: Made by author

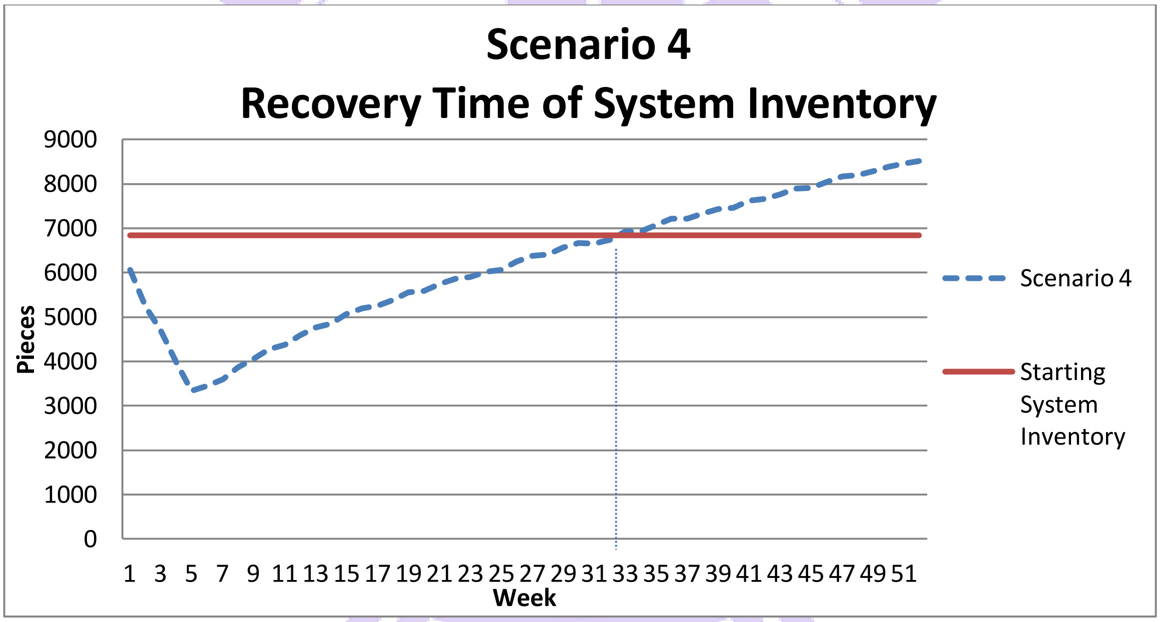

Figure 14. Scenario 4. Recovery Time of System Inventory
Source: Made by author

With the results of recovery time, Scenario 2 present the shortest recovery system time (in week 26) but for inventory level within the 52 weeks of analysis cannot reach the initial level. Instead Scenario 4 which represents a Pull system has better performance after a disruption, and has the capacity to recover the starting inventory and system inventory after an event in a period less than 52 weeks.

Missed to Clients Results

The missed to Clients quantities represent the amount of product from retailer's orders at the end of the year that cannot be sent. This parameter is important to analyze because reflects not only the total amount at the end of one year as presented in Figure 15, but in Figure 16 also we can observe the behavior along 52 weeks. After 52 weeks, the scenario 2 presents a huge amount of total missed to clients, this quantity of products increase over all the year, unlike other simulations where during 10 to 20 weeks presents missed to clients but the following weeks until the end of the simulation period this quantity do not increase.

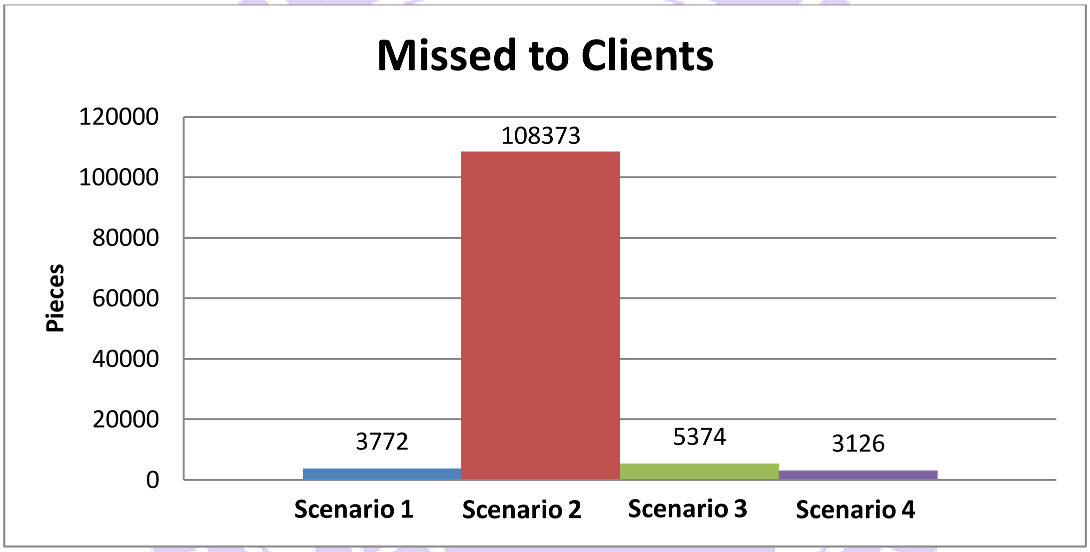

Figure 15. Missed to Clients Total Results
Source: Made by author

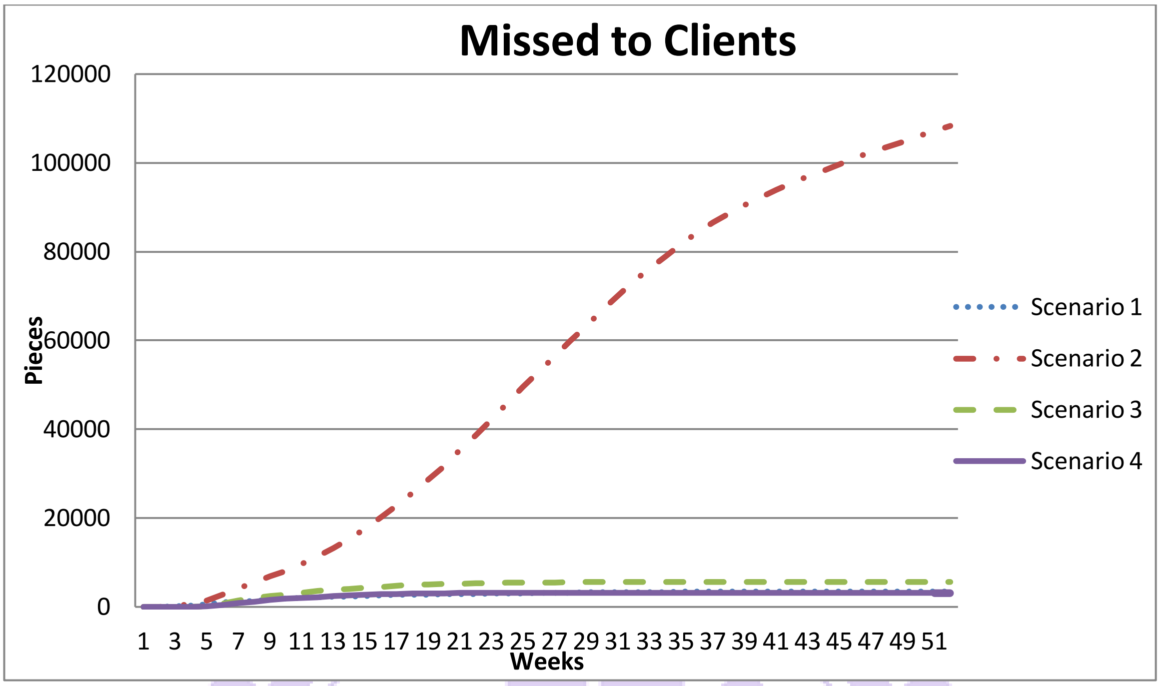

Figure 16. Missed to Clients Weekly Totals
Source: Made by author

Missed to Market Results

The sales opportunities that are lost due to stock out are called missed to market. In these simulations, the scenario who presents more loses on sales of end products to final consumers was Scenario 2 (See Figure 17). Also not only the total missed to market amount on Scenario 2 is higher but on Figure 18 it can be observed the same pattern that Scenario 2 presents in missed to clients graphics, the amount of missed to market pieces during the year will increase until week 52. Although the recovery time parameter report that around week 26 that scenario recover the initial inventory system level, over all year still have lost in sales due to lack of product, indicating that despite the system has lots of product to meet the demand, those products are not placed in the correct region because Scenario 2 is a push-pull system, where the plant does not maintain large amount of finished product, those products are sent directly to the regional centers based on the client's orders.

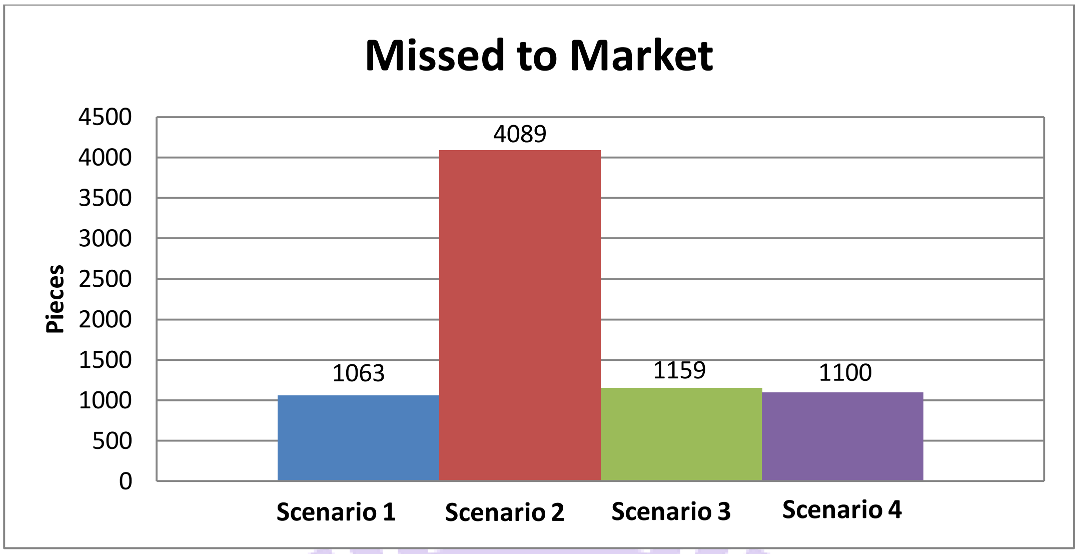

Figure 17. Missed to Market Total Results
Source: Made by author

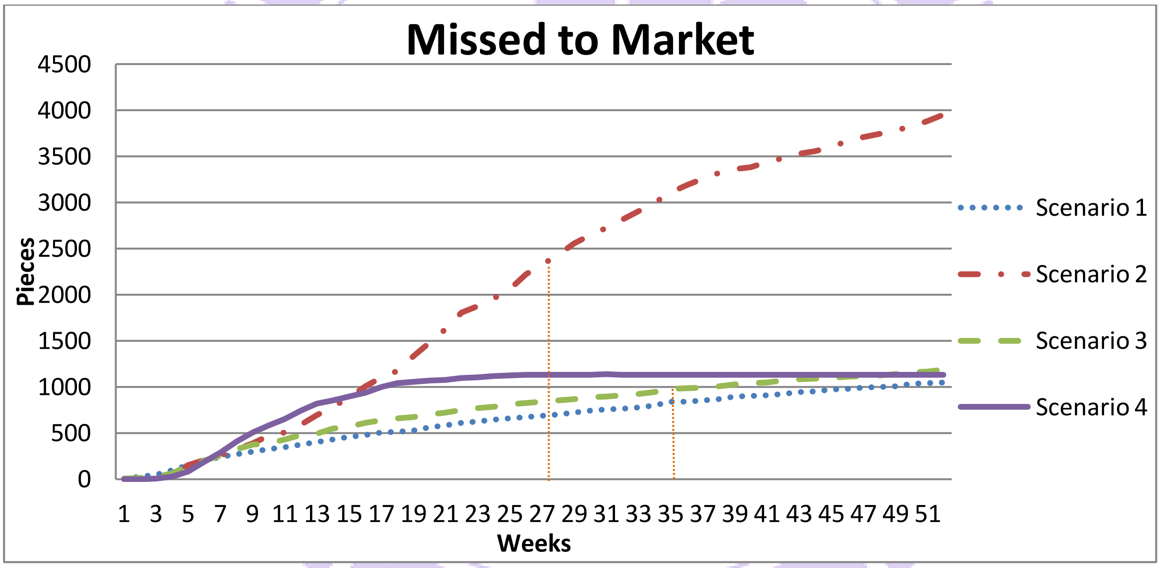

Figure 18. Missed to Market Weekly Totals
Source: Made by author

The tendency of the rest of scenarios is to increase in the total amount of missed to market items, but that increment is not significant compared to the presented on Scenario 2. But is necessary emphasizing in week 33, when the Initial System Inventory Level of Scenario 4 is recovered, the amount of missed to market products remains the same until finish the simulation, which means recover the inventory and also meet demand.

Returns

Since the product is finished it has a lifetime of 30 weeks over all simulations. The value of average returned products is 2,273 pieces for Scenario 1; 2,156 pieces for Scenario 2; Scenario 3 has 1,045 returned pieces; for Scenario 4 is 79 returned pieces (Figure 19).

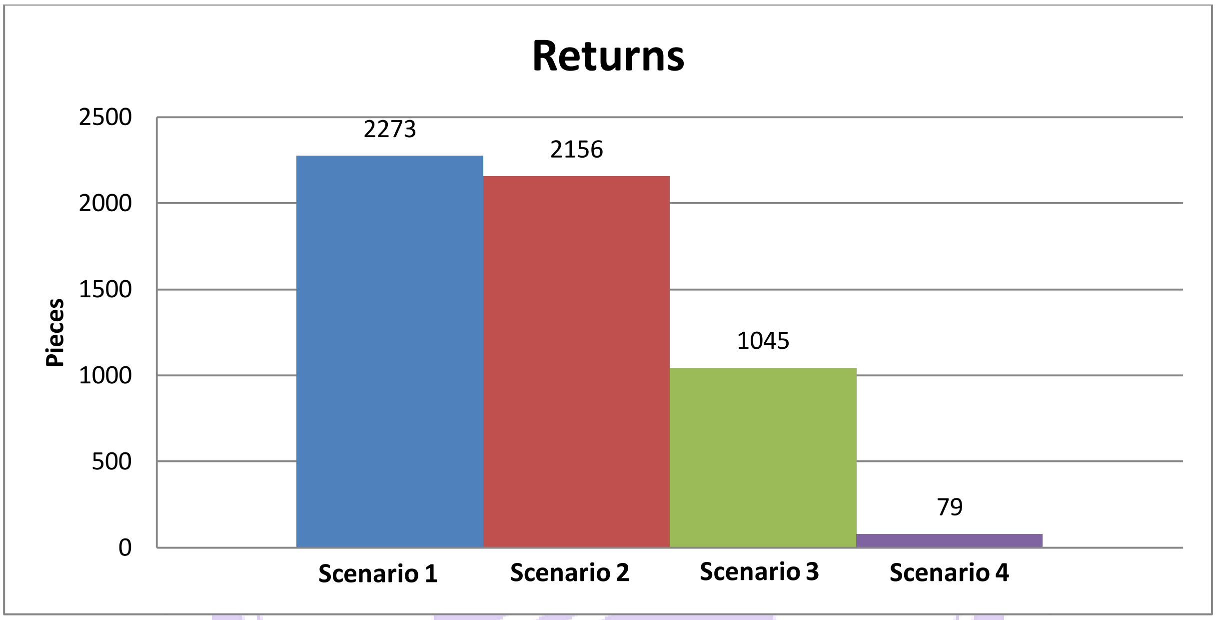

Figure 19. Total Returned Items
Source: Made by author

Scenario 1 and 2 presents higher amount of returned products at the end of the year. That happens because in both simulations the system carry high levels of inventories (6 and 10 weeks of average sales) based on forecasts. Another reason is products need to be distributed to regions because there is no warehouse in the plant, then the products are already sent to regions, but if the market demand changes there is no way to move the products from one region or retailer to another to cover fluctuation on demand. Also with high inventory the product rotation is less, keeping the products in storage for a long time reducing the time when the end consumer can used it.

Scenario 3 shows a reduction in the total amount of returned products. The change in system design (from regional warehouse to central warehouse) causes that the inventory on regions will decrease which also decrease the stock turnover time.

The huge difference in Scenario 4 lies to the fact that inventory levels at retailers are lower than Scenario 3 and also because the orders are made daily based on the consumption of the previous day. The high levels of inventories remain at the plant warehouse.

While Figure 20 shows the comparison of all simulations in the increment of returned products among the 52 weeks.

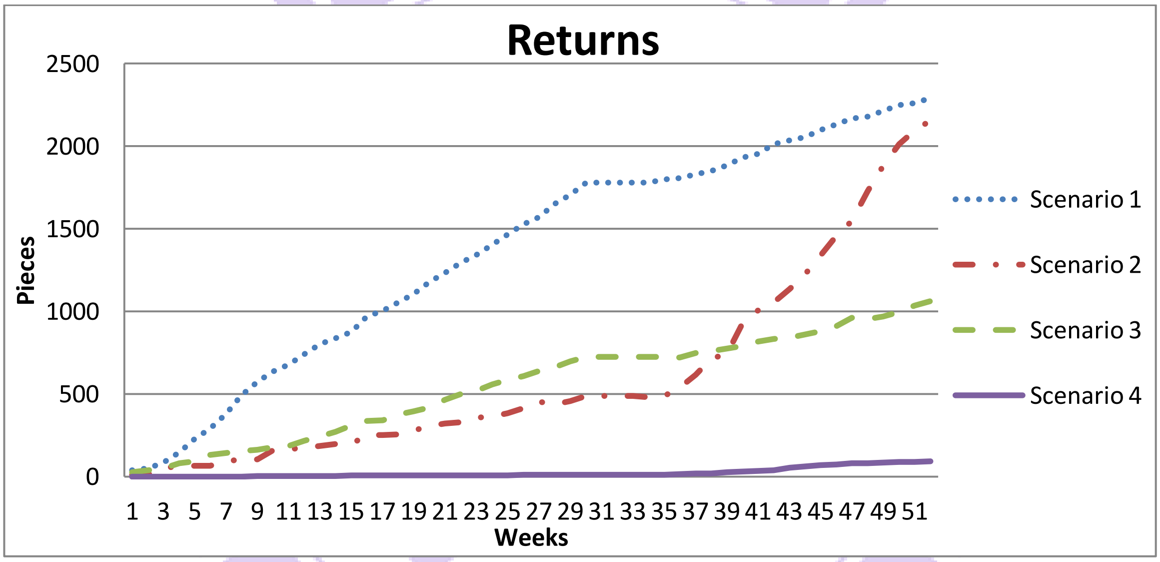

Figure 20. Comparison of Returns during 52 weeks
Source: Made by author

Net Profit

The net profit is the earnings a company has after considered all the expenses (fixes, returns, transport and interest on the inventory); with this parameter will be known if the company is or is not profitable. Scenario 1, has an average net profit at the end of analysis on $ -1,109 which is because the level of inventory over all year is less than the starting inventory, and also because is affected by the high quantity of returned products, compared with total sales the costs incurred by the company are higher than the quantity of products sold to market.

For Scenario 2, the Net Profit amount after 52 weeks is $50,081. Scenario 3 presents $23,900, while Scenario 4 had $52,919 (See Figure 21).

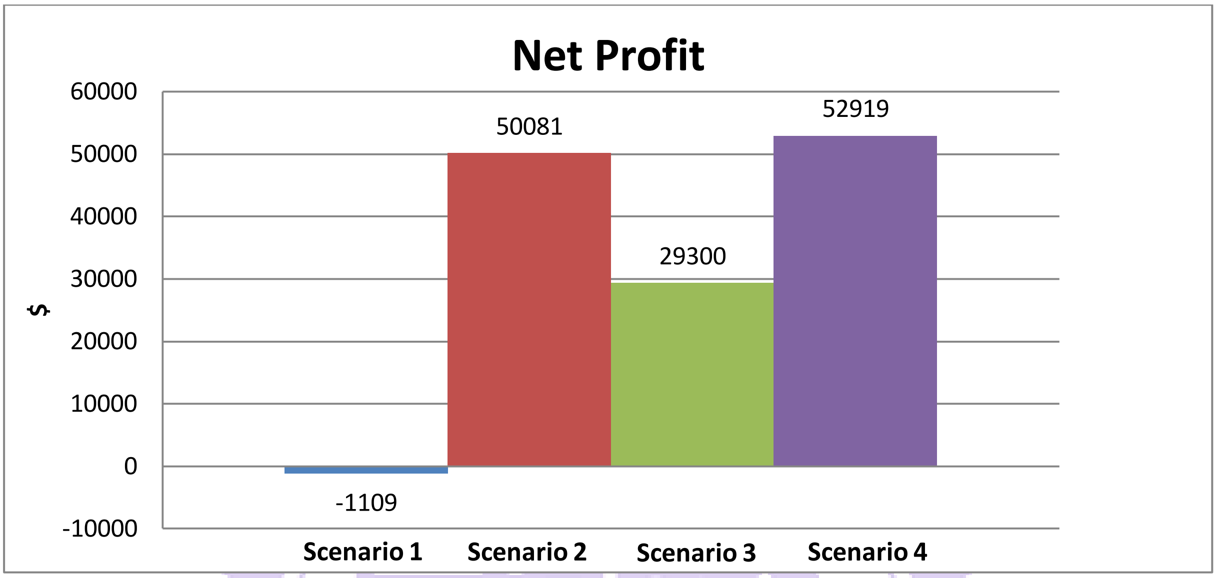

Figure 21. Net Profit Results
Source: Made by author

As can be observed in Figure 22, the behavior of Scenario 2 was increase the net profit over the year but then around week 40 their net profit slightly decreases. That reduction in the Net Profit since week 40 to 52 may be due to the significant increment in the returned products during the same time frame.

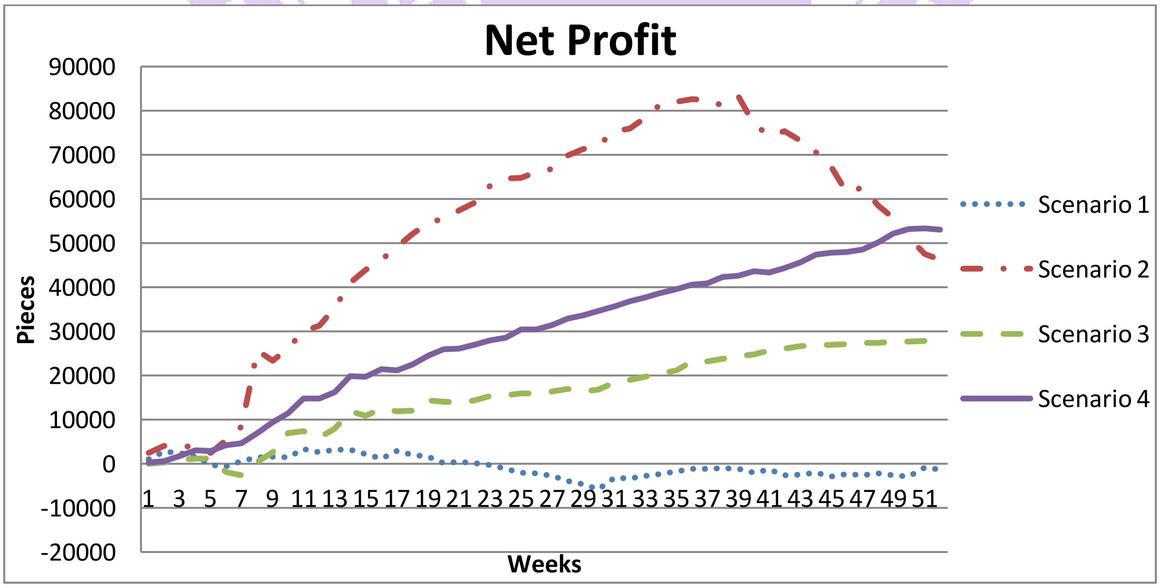

Figure 22. Comparison of Net Profit during 52 weeks
Source: Made by author

Scenario 3 and 4 presents the same behavior; they increase their net profit along the year, with a difference that at week 52 (end of simulation) the average net profit in Scenario 4 is the almost the double as Scenario 3.

In Table 6 Comparison between Scenarios is shown the results of all the parameters analyzed between the scenarios. For Scenario 1, during 52 weeks of performance analysis cannot recover the total system inventory and also at the end of the year the net profit shows that is under \$0, that is to say is in bankruptcy. This means that for this company structure, the push system is not considered as a good option to run the company in order to have the capacity of overcome a disruption of 5 weeks which affects the production in the plant.

Table 6. Comparison between Scenarios

Scenario		1	2	3	4
Recovery Inventory (Weeks)	Mean	>52	>52	44.17	40.80
	S. Dev	-	-	1.98	1.13
Recovery System Inventory (Weeks)	Mean	>52	26.93	41.93	33.10
	S. Dev	-	3.18	2.36	2.29
Missed to market (pieces)	Mean	1063	4089	1159	1100
Missed to Clients (pieces)	Mean	3772	108373	5374	3126
Returns (pieces)	Mean	2273	2156	1045	79
Net Profit (\$)	Mean	-1109	50081	29300	52919

Source: Made by author

Scenario 2 has a recovery system time in week 26, the shortest recovery time between simulations and also has the second higher net profit among simulations.

Scenario 3 in average takes more time to recover from a disruption, around week 41 to back to the system starting level and for the inventory level on week 44. The profits made in a year by Scenario 3 is little more than the half of profits made by scenario 4.

Scenario 4 instead is the scenario which had higher average net profit ($52,919) also both inventories recovers their initial levels before week 52. Due to the structure of the supply chain the amount of missed to clients, missed to market and return products is not that higher than other simulations. With these results it can be proved that the pull supply chain system design is the best option to run a company in order to have the capability to handle small disruptions.

Chapter 6. Conclusion and Extensions

In this final chapter, conclusions of the findings in this study are provided together with recommendations for further research.

Conclusion

Based on the purpose of this study, was compared the behavior of the push, push-pull and pull supply chain system design with the first 5 weeks of disruption and the following recovery time. The tool used to analyze the systems is the AGI Distribution Software developed by Abraham Goldratt Institute.

The results were compared based on performance metrics as recovery inventory and system inventory, quantity of missed to clients, missed to market, return products and the net profit of the manufacturing company. With these results provided by simulations, the pull supply chain system design simulated in Scenario 4, on average presented shorter inventory and system inventory recovery time, less amount of products missed to market, to clients and retuned items compared with the rest of scenarios; also the net profit at the end of the year was higher in the pull system scenario.

The final data also shows that scenario push-pull system represented in Scenario 2 compared with pull system presents shorter system recovery time (Pull system an average of 33.10 weeks and push-pull system 26.93 weeks) and the net profit is slightly the same (Pull system an average of $52,919 and push-pull $50,081). But with a detailed analysis the performance of Scenario 2 is not better than Scenario 4 because Scenario 2 until week 52 still have missed to market and clients which shows that the demand is not been covered even though the inventory level is the same as initially (the products are storage in the wrong place).

Limitations

Despite all the efforts made in this research, limitations still exist in the overall research approach, in the method used, and in the data and tools utilized.

In this study the limitations presented were in the software utilized, since was not flexible to make changes in the parameters were needed to only analyze under a fixed parameters. Besides, changes to improve the system cannot be implemented, and then only could be applied one solution of the problem which was increase the production batch size.

Also the software under an oscillating market in the pull system doesn't allow a disruption of 5 weeks, only until 4 weeks so it couldn't analyze the recovery time if the market behavior changes because will not compare the recovery time after 4 and 5 weeks of disruption.

Extensions to Future Research

Carried more inventory involve cost of holding those pieces and also affect the lifetime of products if they are stock for longer. When the production batch size is increased to recover from an event in the simulations that size it continues throughout the entire analysis period, this will be planned to analyze fairly the performance of all scenarios. This research in order to get results under same condition was used the same production quantity until week 52, despite the system will recover o not the initial inventory level. But it can be seen in Scenarios 2, 3 and 4 after recovery time the inventory levels goes up to the initial level because the production is the same while where after disruption. A recommendation for future studies about recovery time is at the moment the initial level is recovered change the production batch size to the one utilized initially (when no disruption appear), with this it can should get better results of net profit and returned products.

Additionally for future research, it can be analyzed the performance of the scenarios while a disruption appears on a market with oscillated demand to see how it affects the parameters analyzed.

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