Revista EIA, ISSN 1794-1237 / Year XIV / Volume 14 / Issue N.27 / January-June 2017 / pp. 43-62
Technical-scientifical biannual publication / Universidad EIA, Envigado (Colombia)

SYSTEMIC EVALUATION OF A POLICY OF VOLUME FLEXIBILITY IN A PAPAYA DISTRIBUTION SUPPLY CHAIN

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ABSTRACT

Volume flexibility is used in this article to determine responsiveness to changes in the deterioration factors of perishable stages in a supply chain. The main objective of this study is to evaluate the impact of this strategy on two key indicators for network performance, such as logistics costs and service levels. The research involves the operation of a papaya distribution network formed by a producer and a retailer, which is simulated through System Dynamics. A policy of flexibility is achieved, which dramatically improves volume indicators such as the level of service and costs considered in the study. However, using this strategy involves taking on a higher cost of inventory storage and an additional cost of capacity increase.

KEYWORDS: Capacity, Flexibility Volume, Perishables, Supply Chain, Papaya, System Dynamics.

EVALUACIÓN SISTÉMICA DE UNA POLÍTICA DE FLEXIBILIDAD DE VOLUMEN EN UNA CADENA DE SUMINISTRO DISTRIBUIDORA DE PAPAYA

RESUMEN

La flexibilidad de volumen es utilizada en el presente artículo para determinar la capacidad de respuesta ante cambios en los factores de deterioro de un producto perecedero en las etapas de una cadena de suministro. El objetivo principal de este estudio es evaluar el impacto que tiene esta estrategia sobre dos indicadores claves para el desempeño de la red como lo son los costos logísticos y el nivel de servicio. La investigación involucra el funcionamiento de una red de distribución de papaya conformada por un productor y un detallista, la cual es simulada a través de Dinámica de Sistemas. Se logra establecer que una política de flexibilidad de volumen mejora notablemente indicadores como el nivel de servicio y los costos considerados en el estudio; sin embargo, utilizar esta estrategia implica asumir un mayor costo de almacenamiento de inventario y un costo adicional de aumento de capacidad.

PALABRAS CLAVE: Capacidad, flexibilidad de volumen, productos perecederos, cadena de suministro, papaya, Dinámica de Sistemas.

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Paper history:
Paper received: 15-II-2016 / Approved: 26-VI-2017
Available online: August 30, 2017
Open discussion until October 2018

DOI: https://doi.org/10.24050/reia.v14i27.865

AVALIAÇÃO SISTÉMICA DE UMA POLÍTICA DE FLEXIBILIDADE DE VOLUME NUMA CORRENTE DE FORNECIMENTO REVENDEDORA DE MAMÃO

RESUMO

A flexibilidade de volume é utilizada no presente artigo para determinar a capacidade de resposta ante mudanças nos fatores de deterioração de um produto perecível nas etapas de uma corrente de fornecimento; o objetivo principal deste estudo é avaliar o impacto que tem esta estratégia sobre dois indicadores chaves para o desempenho da rede como o são os custos logísticos e o nível de serviço. A investigação envolve o funcionamento de uma rede de distribuição de mamão conformada por um produtor e um detalhista, a qual é simulada através de Dinâmica de Sistemas. Consegue-se estabelecer que uma política de flexibilidade de volume melhora notavelmente indicadores como o nível de serviço e os custos conceituados no estudo; no entanto, utilizar esta estratégia implica assumir um maior custo de armazenamento de inventário e um custo adicional de aumento de capacidade.

PALAVRAS-CHAVE: Capacidade, flexibilidade de volume, produtos perecíveis; corrente de fornecimento; mamão; sistemas dinâmicos.

1. INTRODUCTION

The supply chain can be defined as the entire product value chain, from the supply of the raw goods to the purchase by the final customer (Croom, Romano, & Giannakis, 2000; Jack & Raturi, 2002). Currently, product life cycles, more intense competition and increases in customer expectations have caused a greater complexity in the operation of supply chains (Blome, Schoenherr, & Eckstein, 2014). The increase in uncertainty and risk in global supply chains adds another level of complexity to the operation (Blome, Schoenherr, & Eckstein, 2014). As such, it is necessary to establish structures that lead to a generalization of flexibility, that is, an approach to frameworks that will improve the capacity of a business to adapt or respond to changes (Braunscheidel & Suresh, 2009).

During the previous century, flexibility was focused only on manufacturing operations. However, due to the increase in globalization, the tendency to subcontract and the elevated complexity of the environment, today's research regarding flexibility has extended to include supply chains (Blome et al., 2014). Notwithstanding, a great portion of existing research contains a limited definition of the flexibility of the supply chain and describes flexibility simply as a means to face uncertainty (Stevenson & Spring, 2007). For this reason, some authors such as Holweg (2005) and Kumar, Fantazy, Kumar, & Boyle (2006) state the existence of an urgent need to carry out new empirical research regarding flexibility of the supply chain.

The flexibility associated with the operation of supply chains of perishable goods is considered complex due to the high level of uncertainty generated by the inaccuracy of quantities, times and specifications in final customer demand (Disney & Towill, 2003; Lee, Padmanabhan, & Whang, 1997). This leads to the need for assurance of greater inventory levels at hand by retailers in order to be able to absorb the fluctuations in demand (Stevenson & Spring, 2007) and this way, offer a high service level, that is, to have a low probability of sales at a loss or backorders.

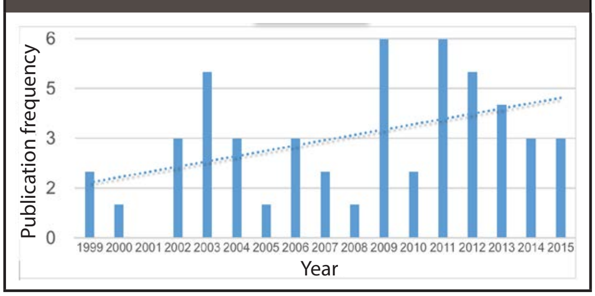
Since flexibility is a tool for the reduction of uncertainty in demand (Blome, Schoenherr, &

Eckstein, 2014), it becomes a fundamental basis for the improvement of the operation of a supply chain of perishables. This, because upon achieving good planning of the demand, there is control of undesired glitches in the system, such as low service level and elevated logistics costs associated with the maintenance of this type of product. For this reason, in this study case, we will approach the problem of flexibility in a supply chain which distributes papaya, through the perspective of an increase in volume flexibility.

In order to achieve volume flexibility characterization in the supply chain of the papaya, a review was done on texts about this concept, using, as search criteria, keywords such as flexibility, capacity increase, adaptability and agility. Attachment 1 shows a table summarizing the most relevant aspects found within the review.

A key aspect to be highlighted within the text search is the fact that flexibility in supply chains has been experiencing a growing interest from the academic field, supported by the greater number of articles each day which approach this problem from different points of view, a fact which has been especially reflected in 2009 and 2011, when a greater number of publications about this topic surged (see **Graph 1**).

Graph 1. Evolution of the concept of flexibility in supply chains



One of the greatest contributions achieved, thanks to text search, is the definition of existing types of flexibility, which, according to Vickery, Calantone, & Dröge (1999) are the following: flexibility of product, volume, new product, distribution and response. This study will use volume flexibility because Vickery et. al. (1999) were able to establish the importance of this type of flexibility in the complement of customer demand and the improvement of response capability. That is, that if a business achieves the creation of a system of volume flexibility, it will tend to have higher levels of service. Additionally, Zhang (2003) establishes that this type of flexibility has a strongly positive relationship with the final customer's satisfaction.

The reason why the papaya is the product of choice for this research is that a study conducted by the Universidad Nacional concluded that this fruit is one of the products which can generate initiatives that will have extensive potential for income generation of people in the North of Valle del Cauca (Castellano et al., 2011). Thus, it can promote the region's economic growth.

The document works as follows: Section 2 describes the methodology with which the problem of the study was approached. Section 3 shows the model's most representative results, developing a sensitivity analysis of some parameters and exhibiting alternative scenarios to the one initially posed. Section 4 consists of a discussion of results and, lastly, Section 5 shows the specific conclusion obtained after the study.

2. METHODOLOGY

System Dynamics were developed by Jay Wright Forrester in 1961 at *Massachusetts Institute of Technology* (MIT) for the purpose of studying, modeling and simulating the behavior of complex social-economic systems. Since then, system dynamics have become efficient in the analysis of all types of policies within any industry. See Forrester (1961); Senge (2006).

This study will approach the volume flexibility analysis of the papaya supply chain through Systems Dynamics, since this tool allows for the clear visualization of information flow of retail orders to the manufacturer, along with delays. This allows for the establishment of a system structure aiming to control undesirable behaviors in the supply chain, such as shortage of the retailer or the loss of trust in the producer. Taco and Robinson (2012) have achieved the establishment of System Dynamics advantages over other types of tools, as discrete event simulations. These advantages include the following:

- It takes a holistic approach to systems by integrating many subsystems.
- It is centered on system policies and structures.
- It uses feedback loops to represent the effects of policy decisions.
- It represents a dynamic vision of cause and effect relationships among the elements of the system.
- It has minimum two data requirements to construct a model.

There are relevant studies where the application of applied System Dynamics to perishables or short-life cycle products is evident. Minegishi & Thiel (2000) intend, by means of System Dynamics, to analyze the control and operation of a food supply chain. The aim is to contribute to the understanding of the complex logistical behavior of a poultry supply chain, emphasizing necessary distribution times in the chain, as well as, how corresponding planning activities should line up to face demand cycles of these products. Higuchi & Troutt (2004) simulate via System Dynamics, the supply chain of the Tamagoshi product by a manufacturer, a market and a retailer for the purpose of helping in decision making in each one of the links of the system.

Contributions found in a previous study by the authors were used here. The study defines and analyses the volume flexibility in perishable product supply chains (Paredes & Salazar, 2014). However, definition and analysis were general, not specific, as in the current study, wherein the subject is the harvest of papaya.

The first step in the methodological process System Dynamics poses consists of the creation of a diagram which relates the main variables and their influence on the rest. This outlining is known as a path diagram. The path of this work will be based on the one previously built by Paredes & Salazar (2014). It will be modified in order to adapt to the specific case of the papaya supply chain.

You can observe how the papaya supply chain works in **Figure 1**. The point marked “1” in the image represents the harvest of papaya. It should be noted that the time in which this product remains in planting varies depending on the type of papaya harvested. Additionally, papaya production can be affected by the number of hectares harvested and the performance per ton that the area planted has. After fulfilling its physiological life 2, the papaya is removed from the plant and taken to a supplier warehouse (represented in the image by point 2) in order to complete its ripening period. When the papaya reaches optimal conditions for consumption by the customer, it is transported in refrigerated vehicles (point 3), trying to conserve product quality as long as possible. The product is delivered to the retailer (point 4), who provides storage for the product to later sell to the final customer (point 5).

In the path diagram, there is interaction among producer, retailer and final customer of the papaya supply chain. The complete path diagram is shown in figure 2. You can see the compensation loops generated in the system and which are represented by the scales. Especially interesting in this study are the perishable characteristics of the product distributed, which is indicated in the path diagram as three external variables of the system, the retailer’s waste factor (associated to product storage) and the producer’s waste factor (associated to product storage, transportation and delivery or lead time). Regarding analysis of this waste rate, in the review made by Li et al. (2010), it is determined that there are some research documents of perishables that consider the rate constant (see: Padmanabhan y Vrat (1995), Bhunia y Maiti (1999)) and others represent this rate as a function dependent on time, with certain random distribution (see: Nita.H. Shah (1993), Sicilia, González, Febles, y Alcaide (2014). For the case study here, the analysis considered is the one with three types of factors constant through time.

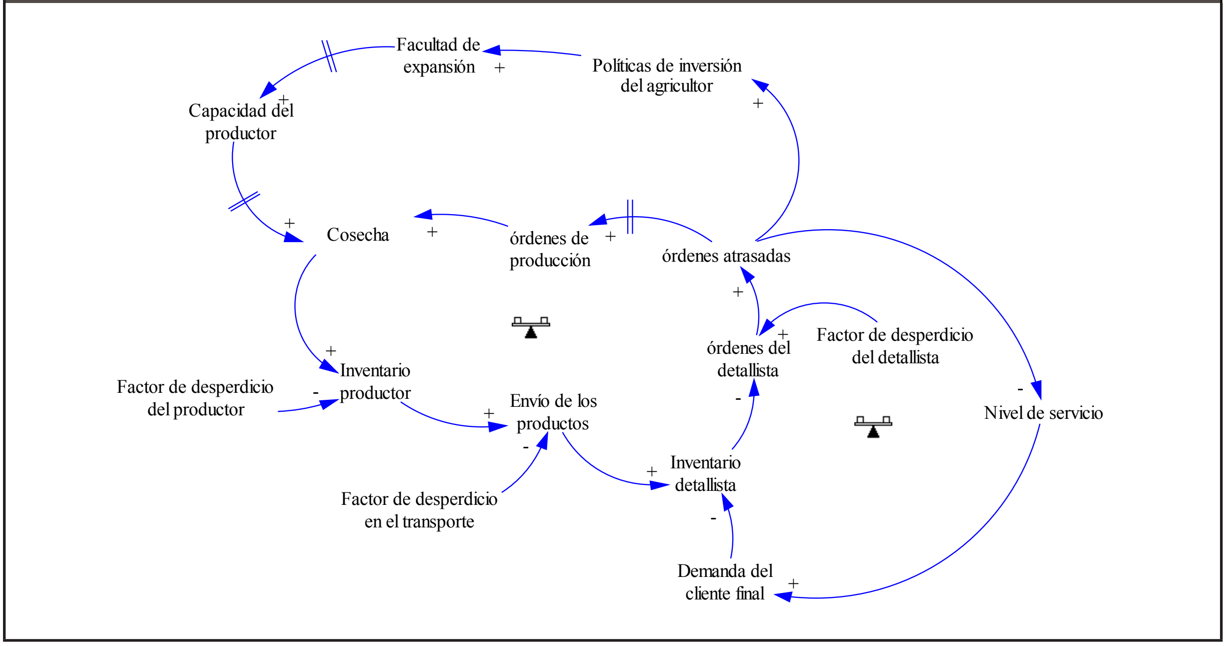
In **Figure 2**, note how the producer begins with an initial capacity which directly affects his harvest. Notwithstanding, it is necessary to clarify there is a delay between the moment of planting and when the harvesting takes place. After the papaya finishes its ripening period in the producer's inventory, it is delivered to the retailer, although, as previously explained, a percentage of the papaya harvested degrades in the producer's inventory, and so cannot be delivered to the retailer.

We can also see in the path diagram, how the demand of the final customer directly affects the retailer's inventory, since it is necessary to accumulate a high level of inventory when demand values are high in order to satisfactorily respond to the customer's needs. This could be a risky measure, because it has a high waste factor associated to keeping products with a short shelf life, as are perishables, for a prolonged period of time.

As available retailer inventory is depleted, this agent will need to emit orders to the producer. However, he should simultaneously keep in mind that, in lieu of the natural decrease perishables have, the retailer should order more than he needs in order to satisfy customer requirements, even though a share of of the product will degrade and be lost en route. The greater the backorders the retailer has accrued, the lesser the customer's perception of his service level. This will cause the customer's demand level to the producer or retailer to decrease.

Figure 1. Description of the supply chain for the Papaya

Figure 2. Path diagram of the Papaya supply chain



As the size and frequency of orders increase, a gridlock of orders occurs and some orders begin to fall behind, since the producer might not have enough capacity to meet the amount of products the retailer demands. This is why the policy of capacity increase investment is oriented toward the acquisition of hectares for planting harvest of papaya. By increasing producer capacity, we seek to improve the service level to the customer by means of a flexible supply chain.

The second step the System Dynamics method poses is the creation of a Forester diagram (stemming from a path diagram). This is built from the basic tool for the simulation of the study. To sum up, the described model includes the following elements and assumptions:

- A supply chain in two links, a retailer and a producer who tend to the daily demand of the final consumer
- Product demand is considered with a perpetual or uniform pattern.
- Only one product is distributed.
- Delivery times between the producer and the customer are 1 to 3 day variables.
- Final customer service is immediate when there is inventory.
- Waste factors are considered in the harvest, the retailer's shop, the producer and transportation from the producer to the retailer's facilities.
- The simulated period is 720 days, equal to two years..

The complete Forrester diagram for the papaya supply chain is shown in figure 3. Zone 1 shows how the grower initially has some hectares that are not being planted and the harvesting process of these have an implicit delay because the papaya seeds are not directly grown in the soil. There is a planting time of these seeds in a nursery. Once the hectare is planted, some time must pass before the fruits can be reaped. It should be noted that once the papaya has been gathered from a determined hectare, it is then available for planting.

In square 2, we can see how the producer supplies a product, which is input flow for his inventory. It should be noted that this production will depend on the initial capacity the producer has, in this study, represented by the number of hectares the farmer acquires and harvests through time. Additionally, once reaping begins, a waste factor associated to product losses at this stage will occur.

A key point in the study is the fact that the product must be in storage for 6 to 8 days before being sent to the retailer. The reason is that the papaya is a climacteric fruit which reaches optimal ripeness point days after being picked from the plantation.

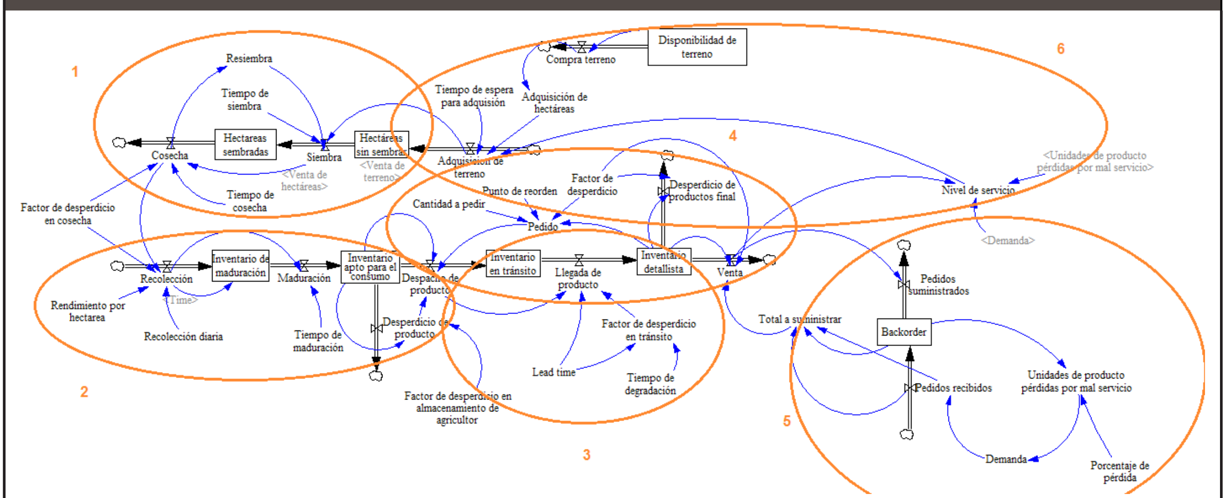
Since the papaya sent by the producer does not immediately reach its destination, a transit inventory must be allocated and managed. Its output will represent the units received to supply the retailer. Due to the waste factor in transportation, which is hindered by the time between each link, amounts received are less than those sent by the producer (See zone 3).

We can observe in circle 4 how the retailer responds to customer demand. However, part of the papaya in storage is degraded and lost, which means it cannot be used for sale. Additionally, the retailer orders each time the actual demand is lower than the re-order point and will place an order looking to cover the average demand within reposition time, along with the inherent waste factor of a perishable such as the papaya.

Since there is a great chance that customer demand will not be met because of degradation of product along the entire supply chain, some orders will be delayed (assuming the customer is willing to wait). And this is the essence of the so called backorder. Notwithstanding, if an order takes too long in being delivered to the customer, said customer will not order from that retailer in the future, perceiving a poor image and low service level (See zone 5).

The indicator that will measure efficiency of the supply chain is the service level, which represents the expected probability of not reaching a situation of zero inventories. The volume flexibility in the model is represented by the acquisition of hectares. The current policy used by the model is the acquisition of a certain number of unplanted hectares when the service level is less than a determined percentage. It should be noted that, because capacity is a strategic decision and not immediately implemented, we will assume that the decision to buy or rent, as well as the adaptation of the land, have an implicit delay. (See demarcation 6).

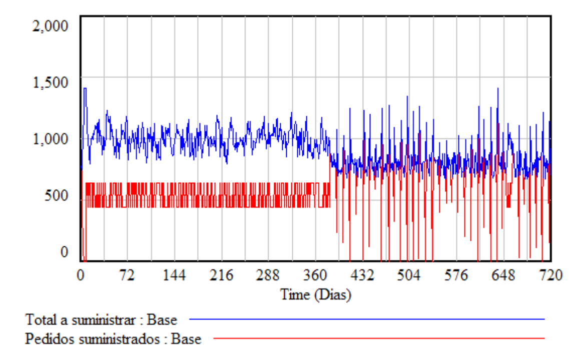
Figure 3. Forrester diagram of the Papaya supply chain



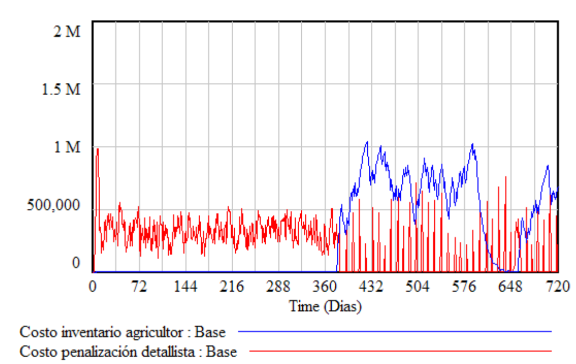
3. RESULTS

In **Graph 2**, we can see that in the first year of simulation, orders supplied, represented by the red line, are much less than the total units that needed to be supplied. This means there are backorders, thereby non-compliment of customer requirements. Notwithstanding, the capacity increase policy implemented begins to have an impact on the performance of the chain beginning year two because the retailer achieves leveling his production with the customer demand.

Graph 2. Total planned deliveries vs. Total actual deliveries supplied



Graph 3. Grower inventory cost vs. Retailer penalties

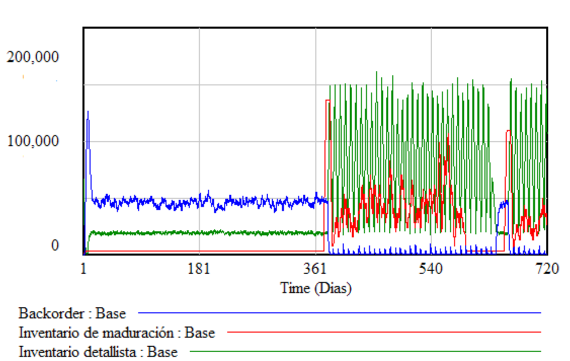


Graph 3 shows how the retailer's penalty cost in the first year is greater than the grower's inventory cost because, initially, the producer does not have enough capacity to satisfy customer needs. At the start the second period, inventory costs begin to dominate, since the volume flexibility increase policy has caused the grower to accumulate a greater quantity of papaya in inventory, aiming to reduce penalty costs generated by non-compliment to customers.

The service level of the retailer at the beginning of the simulation remains below the desired level (45.35% average), which is why the producer is constantly acquiring capacity to improve the service level in the chain. However, this only reflected in the beginning of the second year due to the implicit delay in a capacity increase process. During this last stage, the retailer begins to comply with the units the customer demands, as well as other pending orders, if any exist. This is represented in the near 100% service level. The average service level obtained during the simulation is 64.17%. Albeit not close to the 100% service level objective of all supply chains, this indicator becomes an acceptable one for complex systems.

Lastly, as is evident in **Graph 4**, waste factors in the system generate that during the first year of simulation, customer needs will not be met, thus backorders are greater than the product inventory of the producer, as well as the retailer. This non-compliment in demand leads the retailer to place orders constantly and creates an overvalued demand, which then leads the grower to acquire additional hectares in order to produce and deliver a greater quantity of papaya to the retailer. However, this overestimation of demand causes the acquired capacity by the producer be much greater than the market demand in the second year. This fact is reflected in the high inventory levels reached, not only by the grower, but also by the retailer. This imbalance between real customer demand and that generated by the supply chain actors is known as Whiplash Effect. As such, you can see the emergence of a whiplash effect due to the waste factors more frequent orders generate and the greater volume to the supplier and the links prior to the supplier.

Graph 4. Representation of whiplash effect in a perishable product supply chain



3.1. Sensitivity analysis

After simulating the base model, a sensibility analysis of some of the case models were carried out, aiming to find the influence that each one of these has on the behavior and performance of the papaya supply chain.

Graph 5 shows the appropriate inventory for the grower's consumption, product of the 20% consecutive variation of the initial waste factor in the producer's storage (8%). We can see that from the second year, the volume flexibility model begins to affect the producer's supply of papaya. The inventory level is higher when there is a lower waste factor, due to the lower storage degradation factor. Additionally, the higher the producer's inventory, the lower the number of papaya deliveries to the retailer, which causes backorders to increase an average of up to 99/ compared to the initial case. (See **Table 1**).

TABLE 1. BACKORDER LEVEL AGAINST A WASTE FACTOR VARIATION IN STORAGE

Waste factor	Maximum	Average	Variation with respect to initial case
48%	1424	576	99%
28%	1416	440	52%
8%	1408	290	0%

TABLE 2. LOSS OF DEMAND INDICATORS AGAINST A WASTE VARIATION FACTOR OF THE RETAILER

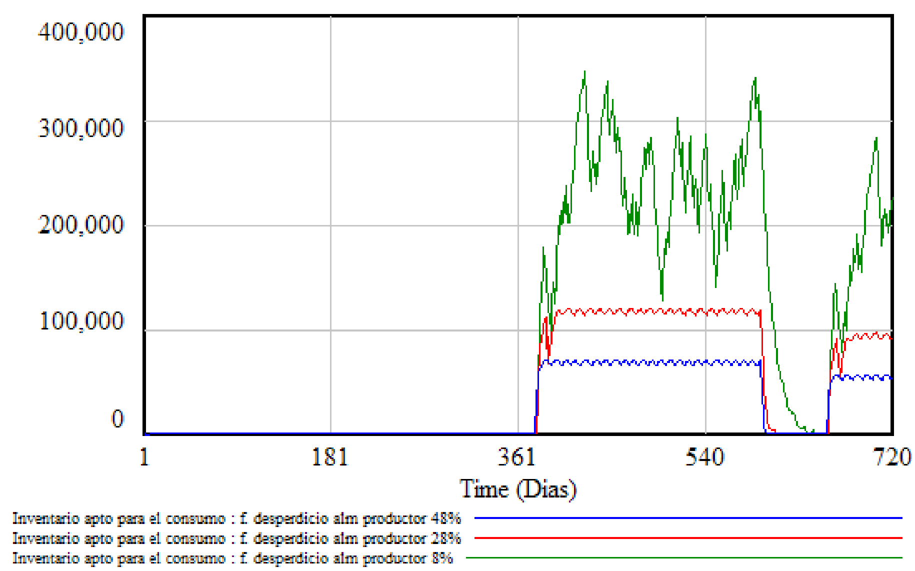
Waste factor	Maximum (papayas)	Average (papayas)	Variation with regard to initial case
45%	784	337	122%
25%	771	244	60%
5%	739	152	0%

Graph 6 shows cultivated hectares through time, resulting in a 20% variation of the initial waste factor (5%) in the retailer's storage. We can see that from day 150 (represented by a yellow line), capacity increase decisions begin to be noticeable. As the waste factor reaches higher levels, a greater quantity of papaya in the retailer's warehouse is lost. This leads to the retailer placing constant and larger orders since he cannot cover his customer's demand with what little is left in his inventory. When the grower perceives that increase in the retailer's orders and the low service level he is offering his customer, he feels he has no choice but to acquire hectares in order to supply a greater number of papaya to the chain. In other words, the higher the waste factor associated to the retailer's storage, the higher the cultivated hectares by the grower. However, since the producer has a limit in the available land he can cultivate, there comes a time when he, despite large waste amounts, will not be able to plant any more hectares.

Since the waste factor in the retailer's storage is higher, his demand planning is harmed due to the fact he now has to order a greater number of papaya to cover the same demand. This, because so much product is lost during the supply chain route. In turn, this leads to a greater proportionate loss in unit demand of some customers (up to 122% more than the initial case, as shown in table 2), because of the retailer's constant non-compliment of demand. For example, while, in the initial case, where there was a product deterioration factor of 5% in storage, an average demand of 152 papayas were lost. The scenario where this amount increases to 45% causes a loss in demand of 337 papayas.

Lastly, a simultaneous variation of 10 and 20% was carried out to each degradation factor of the current papaya supply. **Table 3** shows how when the waste factor in the supply chain is higher, a greater amount of product in the chain is lost. This causes the retailer to be unable to fill his orders in a greater proportion, and this affects the penalty costs associated to shortages, since in a worst case scenario, costs associated to non-fulfillment of orders increase up to 113%, which leads to a decrease in company profits.

Graph 5. Behavior of grower inventory against a waste factor variation in the producer's warehouse



Graph 6. Cultivated hectares against a waste variation factor at the retailer's warehouse

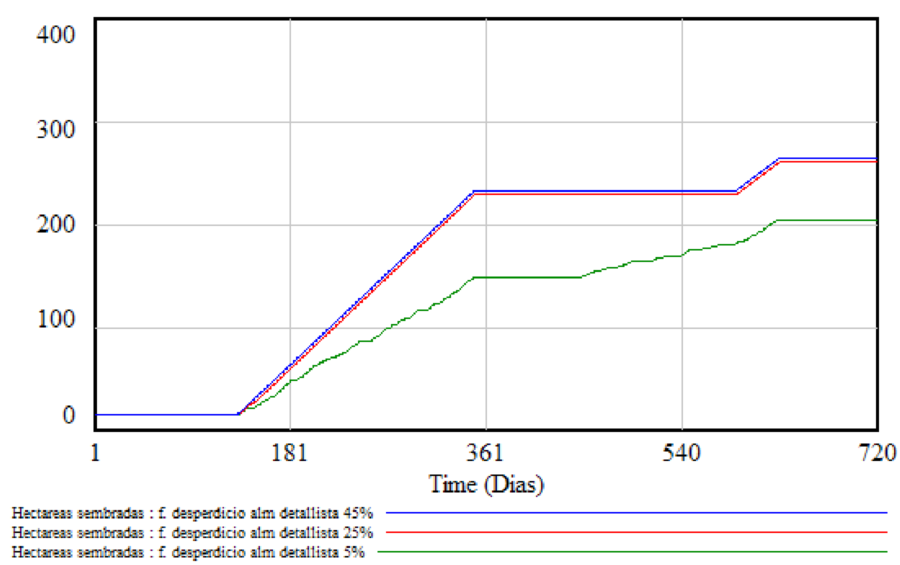
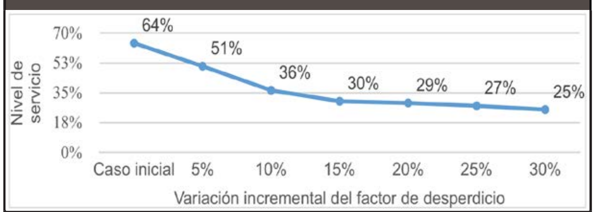


TABLE 3. RETAILER PENALTY COST AGAINST AN OVERALL WASTE VARIATION OF THE SUPPLY CHAIN

Waste variation	Maximum	Average	Variation with respect to initial case
20%	$ 1,033,403	$ 432,250	113%
10%	$ 1,012,669	$ 335,073	65%
Base case	$ 985,414	$ 202,692	0%

Graph 7 shows the impact on the service level, which has an increasing variation of 5% in each of the waste factors in the chain. We can see in this graph that an increase in papaya waste in the supply chain causes the service level to be lower with respect to the original case. This aspect makes it necessary to have strict control of these types of chains, in order to reduce factors which generate degradation of the papaya, thus improving the service level of the entire system.

Graph 7. Behavior of service level against a waste variation generated in the supply chain



Graph 8 shows the behavior of the service level with respect to the cost entailed in the achievement of said service level. First, we can see that a service level of 100% is utopic due to the fact it is practically impossible to achieve because of the randomness of customer demand.

In addition, we can see that there is a moment in which an investment can generate a meaningful improvement in service level, as seen in the fact that the change in the cost variable is lower than the change in service level. The moment the service level varies in a lesser proportion than the cost, the percentage of additional income obtained because of improvement in customer service satisfaction must be evaluated. This evaluation is necessary to be able to assess if the investment made in improving end customer satisfaction is compensated with higher revenue due to product sales.

Graph 8. Service level behavior against investment cost in additional capital

3.2. Scenario analysis

Finally, two different scenarios from the original were considered in order to see the impact of these assumptions within the model.

The first scenario consists of making a comparative analysis between two supply chains, one managing perishable products and the other which doesn't. The aim was to identify the impact the waste waste consideration has in terms of costs and service level. In this scenario, the need to increase capacity is more frequent in a supply chain involving perishables, since the retailer's inventory is lower. A major non-compliment of unit demand by the customer is generated, thus causing service to reach critical levels. This leads the retailer's penalty cost to be greater (approximately by 773%) in a supply chain that distributes perishables. (See **Table 4**).

TABLE 4. RETAILER PENALTY COST IN A SUPPLY CHAIN WITH AND WITHOUT WASTE

Scenario	Average	Variation
CS without waste	$ 23,228	0%
CS with waste	$ 202,692	773%

TABLE 5. LOGISTICAL COSTS IN A SUPPLY CHAIN WITH AND WITHOUT WASTE

Scenario	Average	Variation	Standard deviation	Average service level
CS without waste	$ 51,460	0%	103,742	94.71%
CS with waste	$ 520,749	912%	262,630	64.17%

When the supplier sees the low service levels the retailer is getting, he begins to implement volume flexibility policies, specifically, the increase in capacity, which, in this case is cultivating a greater amount of papaya hectares. This causes the number of cropped hectares in a perishable product supply chain to be greater in comparison to a supply chain of non-perishables. As a consequence, the constant implementation of the volume flexibility policy in supply chains of perishable products generates a greater cost associated to the increase in capacity compared to a logistics system which manages non-perishables.

Comparing the service in a supply chain which handles perishable goods, such as papaya, to a distribution network which does not have associated waste, we can see how the service level is lower in the former (64.17% vs. 94.71%. See table 6). This is because, in the case of a perishable product supply chain, the retailer must not only take into account customer demand at the time of placing orders, but also the waste factor generated in the entire system. This means that, if the retailer does not plan his demand well, he might get scenarios of sales losses or backorders which end up hindering the service level of the entire chain.

Lastly, as **Table 5** shows, a perishable products supply chain involves higher logistics costs (by approximately 912%) generated by more frequent orders, higher storage costs and greater penalties for low service levels, all compared to a non-perishable distribution network. Moreover, the cost variation through time is more noticeable in a supply chain for perishables. This fact is reflected in the greater value achieved by the standard deviation for the system in which waste is considered.

In the second scenario, two supply chains for perishable goods were compared. The first, in which a volume flexibility policy is applied, is analyzed from the point of view of the supplier's production capacity. The second is a system in which a volume flexibility policy does not exist. This comparison is done for the purpose of establishing the impact of a volume flexibility policy on some supply chain performance indicators, such as the service level and logistics costs. The most relevant results are shown below.

Table 6 shows how units pending delivery to the customer are greater in the case where the volume flexibility policy is not applied. They are greater because the supplier never increases his production capacity in order to generate greater flow in the product to the retailer. This causes the continuation of non-compliment to the customer and that service levels reach critical numbers compared to a supply chain wherein the volume flexibility policy is applied. **Table 6** shows how the average service level of a perishable goods supply chain that does not use a volume flexibility policy is much lower compared to the case in which this strategy is applied (49.3% vs. 64.2%).

TABLE 6. AVERAGE BACKORDER AND AVERAGE SERVICE LEVEL IN A SUPPLY CHAIN WITH AND WITHOUT A VOLUME FLEXIBILITY POLICY

Scenario	Average backorders	Average service level
CS without volume flexibility policy	436.7	49.3%
CS with volume flexibility policy	289.6	64.2%

In the case in which a supply chain manages an increase in capacity, the supplier incurs in a lesser penalty, compared to the case in which no flexibility policy is used. (See **Table 7**). This is because deliveries to the retailer are adjusted to a greater degree to the order placed. This, in turn, causes the retailer who does not apply a flexibility strategy to have a greater cost associated to poor customer service. (See **Table 7**). This is due to the fact that the supplier does not increase his orders at any time, since his capacity is fixed and limited.

TABLE 7. IMPACT OF A VOLUME FLEXIBILITY POLICY ON THE AVERAGE PENALTY COST OF THE PRODUCER AND RETAILER

Scenario	Average cost of producer penalty	Average cost of retailer penalty
CS without volume flexibility policy	305,655	18,090
CS with volume flexibility policy	202,692	13,296

An aspect to note is how having a capacity increase policy increases producer inventory levels, which causes his maintenance cost to be higher in comparison to a supplier who does not use a volume flexibility policy.

In conclusion, one can affirm that the volume flexibility policy noticeably improves indicators, such as service level and costs associated to producer and retailer penalties. However, using this strategy implies assuming higher inventory costs, as well as an additional increase in capacity, which is represented in the simulation by the amount of purchase or rent of each hectare.

4. CONCLUSIONS

The volume flexibility analysis in perishable product supply chains, made during this study seeks to aid in the unification and systemizing of a series of concepts related to management of this type of chains, such as demand planning, ordering policies, inventory levels, etc.

It has been found that flexibility decisions have to consider not only the behavior of the demand, but also the type of product to be distributed. The perishable characteristics of a product influence orders, as well as the needed capacity to supply them. We foresee a whiplash effect due to the consideration of waste factors that more frequent and greater volume orders to the supplier generate and the prior links. Another aspect influencing the retailer's inventory management is the perishable factor associated to the distribution process. The negative influence on inventory control is highlighted since said waste factors distort final customer demand information for all integrated firms of a supply chain.

We can pose a delay exists between management's decision to increase supplier capacity and the positive effect it can have on the final customer service levels. For this specific case study, we found that the benefit begins to arise after one year of operation.

System Dynamics are considered relevant as management input for impact analyses policy decisions, such as this study's capacity increase upon a determined level of backorders. It is possible to evaluate other policies as the flow of information among the chain participants, with which a wide study range, yet unexplored, on flexibility is established. Moreover, it is supported by the same bibliographic review made during this case study, which highlights the lack of study on this subject.

The management of perishable product supply chains such as papaya is much more complex than one of a non-perishable mainly because of the distortion in demand, which causes the deterioration of the product all along the chain.

For any supply chain to reach a 100% service level is utopic goal because, in reality, it is practically impossible. This is mainly due to the to the randomness present in customer demand. Additionally, we can observe that there is a moment in which an investment can generate a significant improvement in the service level, proven by the fact that a change in the cost variable is less than the change in the service level. At the moment the service varies in a lesser proportion than the cost, we must evaluate what percentage of additional income is obtained due to the improvement in the satifaction of customer needs. This is in order to compare if the investment made to improve final customer satisfaction is compensated by greater income due to product sales.

A perishable product supply chain involves higher costs in logistics generated by more frequent orders, higher storage costs and greater penalties for low service level, compared to a non-perishable distribution grid.

The volume flexibility model notably improves indicators, such as the service level and costs associated to producer and retailer penalties. However, using this strategy implies assuming a greater cost for inventory warehousing and an additional cost of capacity increase, which is represented in the simulation by the value the purchase or rental of hectares has.

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ANNEXES

Annex 1. Summary chart of review of terms regarding flexibility concept and its applications

TO REFERENCE THIS ARTICLE / PARA CITAR ESTE ARTÍCULO / PARA CITAR ESTE ARTIGO /

Paredes Rodríguez, A.M.; Salazar Ramos, A.F. (2017). Systemic Evaluation of a Policy of Volume Flexibility in a Papaya Distribution Supply Chain. *Revista EIA*, 14(27), January-June, pp. 43-62. [Online]. Available at: https://doi.org/10.24050/reia.v14i27.865

Annex 1. Summary chart of review of terms regarding flexibility concept and its applications

Item	Name	Authors	Journal	Year	Form of volume flexibility	Field	Product	Volume	New product	Distribution	Response	Industry	Other characteristics	Demand pattern	Case study	Method used
1	Sources of volume flexibility and their impact on performance	Jack & Raturi	Journal of Operations Management	2002	Production adjustment capacity	NA		x				NA	NA	NA	Revision	NA
2	Capacity augmentation of a supply chain for a short lifecycle product: A system dynamics framework	Kamath & Roy	European Journal of Operational Research	2007	Production adjustment capacity	Supply chain		x			x	Short life cycle products	NA	Stochastic	Theoretical	Simulation through System Dynamics
3	Integrating effective flexibility measures into a strategic supply chain planning model	Das	European Journal of Operational Research	2011	Production adjustment capacity	Supply chain	x	x		x		NA	NA	Stochastic	Theoretical	Optimization
4	Manufacturing flexibility: defining and analyzing relationships among competence, capability, and customer satisfaction	Zhang, Vonderembse & Lim	Journal of Operations Management	2003	Production adjustment capacity	NA	x	x	x			NA	NA	NA	Revision	NA
5	Volume and Mix Flexibility Evaluation of Lean Production Systems	Metternich, Böllhoff, Seifermann & Beck	Procedia CIRP	2013	Production adjustment capacity	Manufacturing	x	x				NA	Lean Manufacturing	Deterministic	Practical	Analytical model
6	Volume Flexible Strategies in Health Services: A Research Framework	Jack & Powers	Production & Operations Management	2009	Production adjustment capacity	Services		x				NA	NA	Stochastic	Practical	NA
7	A method to enhance volume flexibility in JIT production control	Moattar Husseini, O'Brien & Hosseini	International Journal of Production Economics	2006	Production adjustment capacity	Manufacturing		x				NA	JIT	Stochastic	Theoretical	Optimization
8	Flexibility configurations: Empirical analysis of volume and product mix flexibility	Hallgren & Olhager	Omega	2009	Production adjustment capacity	Manufacturing	x	x				NA	NA	Stochastic	Practical	NA
9	Green Supply Chain Model with Product Remanufacturing under Volume Flexible Environment	Singh & Singh	Procedia Technology	2013	Product reutilization	Supply chain		x	x		x	Short life cycle products	NA	Deterministic	Theoretical	Differential Equations
10	Measuring and Comparing Volume Flexibility in the Capital Goods Industry	Jack & Raturi	Production & Operations Management	2009	Production adjustment capacity	Manufacturing		x				NA	NA	NA	Practical	NA
11	Relations between volume flexibility and part cost in assembly lines	Jönsson, Andersson & Ståhl	Robotics and Computer-Integrated Manufacturing	2011	Production adjustment capacity	Manufacturing		x				NA	JIT	Stochastic	Theoretical	Analytical model

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12	Hedging strategic flexibility in the distribution optimization problem	Lin & Chen	Omega	2009	Production adjustment capacity	Supply chain		x		x		Short life cycle products	MTS	Stochastic	Practical	Analytical model
13	A method to determine customer-specific volume flexibility in a supply network	Reinhart & Schellmann	Production Engineering	2011	Production adjustment capacity	Supply chain		x				NA	NA	Stochastic	Theoretical	Simulation
14	Optimal Production Policy for a Volume-Flexibility Supply-Chain System	Feng & Zhang	Production Engineering	2005	Production adjustment capacity	Supply chain		x				NA	NA	Deterministic	Theoretical	Differential Equations
15	Optimal production policy for a manufacturing system with volume flexibility in a supply chain under lumpy demand	Xu, Jiang, Feng & Tian	European Journal of Operational Research	2012	Production adjustment capacity	Supply chain		x				NA	NA	Deterministic	Theoretical	Differential Equations
16	Drivers of volume flexibility requirements in manufacturing plants	Oke	European Journal of Operational Research	2003	Production adjustment capacity	Manufacturing		x				Short life cycle products	NA	NA	Revision	NA
17	Volume flexibility: the agile manufacturing conundrum	Yusuf, Adeleye & Sivayoganathan	European Journal of Operational Research	2003	Production adjustment capacity	Manufacturing		x				NA	NA	NA	Revision	NA
18	Mix flexibility and volume flexibility in a build-to-order environment	Salvador, Rungtusanatham, Forza & Trentin	International Journal of Operations & Production Management	2007	Production adjustment capacity	Supply chain	x	x				Long life cycle products	MTO	Stochastic	Practical	Analytical model
19	Capacity Flexibility of Chemical Plants	Seifert, Lesniak, Sievers, Schembecker & Bramsiepe	International Journal of Operations & Production Management	2014	Production adjustment capacity	Manufacturing		x				Short life cycle products	NA	Deterministic	Practical	Analytical model
20	Managing capacity flexibility in make-to-order production environments	Tanrisever, Morrice & Morton	International Journal of Operations & Production Management	2012	Production adjustment capacity	Manufacturing	x	x				NA	MTO	Stochastic	Theoretical	Optimization
21	Volume Flexibility in Services: The Costs and Benefits of Flexible Labor Resources	Kesavan, Staats & Gilland	Management Science	2014	Production adjustment capacity	Services		x				NA	NA	Deterministic	Practical	Analytical model
22	Impact of Inventory Management Flexibility on Service Flexibility and from Mainland Performance : Evidence from Mainland Chinese Firms	Song & Song	Transportation Journal	2009	Production adjustment capacity	Supply chain		x				NA	MTS	NA	Practical	Analytical model
23	Production Capacity Modeling of Alternative , Nonidentical , Flexible Machines	Liberopoulos	The international Journal of flexible manufacturing systems	2002	Production adjustment capacity	Manufacturing	x					NA	NA	NA	Theoretical	Optimization
24	Demand scenario analysis and planned capacity expansion: A system dynamics framework	Suryani, Chou, Hartono, & Chen	Simulation Modelling Practice and Theory	2010	Production adjustment capacity	Manufacturing		x				Long life cycle products	NA	Stochastic	Practical	Simulation through System Dynamics

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25	Dynamic simulation of the supply chain for a short life cycle product—Lessons from the Tamagotchi case	Higuchi & Troutt	Computers & Operations Research	2004	Production adjustment capacity	Supply chain		x			x	Short life cycle products	NA	Stochastic	Practical	Simulation through System Dynamicssystems
26	A Citation Analysis of the Research on Manufacturing and Supply Chain Flexibility	Seebacher & Winkler	International Journal of Production Research	2013	Production adjustment capacity	Supply chain	x	x	x	x	x	NA	NA	NA	Revision	NA
27	A conceptual model of supply chain flexibility	Duclos, Vokurka & Lummus	Industrial Management & Data Systems	2003	Production adjustment capacity	Supply chain	x	x	x	x	x	NA	NA	NA	Revision	NA
28	An Empirical Investigation of the Impact of Strategic Sourcing and Flexibility on Firm's Supply Chain Agility	Chiang, Kocabasoglu-Hillmer & Suresh	International Journal of Operations & Production Management	2012	Production adjustment capacity	Supply chain	x		x	x		NA	NA	Stochastic	Practical	Analytical model
29	"Supply Chain 2.0": managing supply chains in the era of turbulence	Christopher & Holweg	International Journal of Physical Distribution & Logistics Management	2011	Production adjustment capacity	Supply chain		x	x	x		NA	NA	Stochastic	Practical	NA
30	Creating agile supply chains in the fashion industry	Christopher, Lowson & Peck	International Journal of Retail & Distribution Management	2004	Production adjustment capacity	Supply chain					x	Short life cycle products	NA	Stochastic	Theoretical	Analytical model
31	Improving Value Chain Flexibility and Adaptability in Build-to-Order Environments	Engelhardt-Nowitzki	International Journal of Physical Distribution & Logistics Management	2012	Production adjustment capacity	Supply chain	x	x		x	x	NA	MTO	Stochastic	Practical	Analytical model
32	Flexibility Configurations for the Supply Chain Management	Garavelli	International Journal of Production Economics	2003	Production adjustment capacity	Supply chain	x			x		NA	NA	Stochastic	Theoretical	Simulation
33	Flexible kanbans to enhance volume flexibility in a JIT environment: a simulation based comparison via ANNs	Guneri, Kuzu & Taskin Gumus	International Journal of Production Research	2009	Production adjustment capacity	Manufacturing		x				NA	JIT	Stochastic	Theoretical	Simulation
34	Measuring and comparing volume flexibility across Indian firms.	Srivastava & Bansal	International Journal of Business Performance Management.	2013	Production adjustment capacity	Manufacturing	x	x				NA	NA	Deterministic	Practical	Analytical model
35	Information technology investments and volume-flexibility in production systems	Khouja & Kumar	International Journal of Production Research	2002	Production adjustment capacity	Supply chain		x				NA	NA	Stochastic	Theoretical	Simulation
36	Effect of purchase volume flexibility and purchase mix flexibility on e-procurement performance: An analysis of two perspectives	Devaraj, Vaidyanathan & Mishra	Journal of Operations Management	2012	Production adjustment capacity	Supply chain	x	x				NA	NA	Stochastic	Theoretical	Analytical model
37	Supply Chain Models with Imperfect Production Process and Volume Flexibility Under Inflation	Singh & Urvashi	The IUP Journal of Supply Chain Management	2010	Inventory management	Supply chain		x				NA	NA	Stochastic	Theoretical	Differential Equations

Annex 1. Summary chart of review of terms regarding flexibility concept and its applications

38	A multi-tier study on supply chain flexibility in the automotive industry.	Thomé, Scavarda, Pires, Ceryno & Klingebiel	International Journal of Production Economics	2014	Production adjustment capacity	Supply chain	x		x			Long life cycle products	NA	Deterministic	Practical	Analytical model
39	The Timing of Capacity Investment with Lead Times: When Do Firms Act in Unison?	Anderson & Sunny Yang	Production & Operations Management	2015	Production adjustment capacity	Manufacturing		x				NA	NA	Stochastic	Theoretical	Analytical model
40	Volume Flexibility, Product Flexibility, or Both: The Role of Demand Correlation and Product Substitution.	Goyal & Netessine	Manufacturing & Service Operations Management	2011	Production adjustment capacity	Manufacturing	x	x				NA	NA	Stochastic	Theoretical	Differential Equations
41	European market integration for gas? Volume flexibility and political risk.	Asche, Osmundsen &Tveterås	Energy Economics	2000	Production adjustment capacity	Manufacturing		x				NA	NA	Deterministic	Practical	Analytical model
42	Managerial perceptions on volume flexible strategies and performance in health care services	Jack & Powers	Management Research News	2006	Production adjustment capacity	Services		x				NA	NA	Stochastic	Practical	Analytical model
43	Creating a volume-flexible firm.	Jack & Raturi	Business Horizons	2004	Production adjustment capacity	Manufacturing		x				NA	NA	Stochastic	Practical	Analytical model
44	Flexibility in global supply chain: modeling the enablers	Kumar, Shankar & Yadav	Journal of Modelling in Management	2008	Production adjustment capacity	Supply chain		x		x		NA	NA	Stochastic	Practical	Analytical model
45	Flexibility of wind power industry chain for environmental turbulence: A matching model study	Zhao, Zhu & Zuo	Renewable Energy	2015	Production adjustment capacity	Supply chain	x	x				NA	NA	Deterministic	Practical	Analytical model
46	A capability approach to evaluate supply chain flexibility	Seebacher & Winkler	International Journal of Production Economics	2015	Production adjustment capacity	Supply chain	x	x	x	x		NA	NA	Stochastic	Theoretical	Analytical model
47	Supply Chain Flexibility: An Empirical Study	Vickery, Calantone & Droge	Journal of Supply Chain Management	1999	Production adjustment capacity	Supply chain	x	x	x	x	x	Productos de ciclo de vida prolongada	NA	NA	Revision	NA
48	International supply chain agility - Tradeoffs between flexibility and uncertainty	Prater, Biehl & Alan	International Journal of Operations & Production Management	2006	Production adjustment capacity	Supply chain		x		x		NA	NA	Stochastic	Practical	Analytical model
49	Leagility: Integrating the lean and agile manufacturing paradigms in the total supply chain	Ben, Naim & Berry	International Journal of Production Economics	1999	Production adjustment capacity	Supply chain	x	x		x		Productos de ciclo de vida corto	Lean Manufacturing	Stochastic	Practical	Analytical model
50	Supply chain flexibility in an uncertain environment: exploratory findings from five case studies	Yi, Ngai & Moon	Supply Chain Management: An International Journal	2011	Production adjustment capacity	Supply chain		x			x	Productos de ciclo de vida prolongada	NA	Stochastic	Practical	Analytical model