Raw Material Supply Configuration with Short Shelf Life in a Production Scenario MTS/MTO Minimizing Operational Risk and Cost

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Abstract

Supply chains face challenges associated with operations natural conditions and products characteristics. There is a growing trend in the new risk identification that may be associated with public health, socioeconomic and environmental factors, which condition productive activities planning and execution. SCRM aims to identifying, measuring and mitigating the risks in organizations. We developed a raw material supply methodology that allows defining material flow management policies (MTS, MTO), considering operating risks and costs. We identify risks and inventory positioning criteria with experts help. Subsequently, we measure risk through a system dynamics simulation model and mitigation actions, through valorized scenarios that produce the raw material supply configuration with a short shelf life. This methodology was evaluated in a Colombian meat products company. We compared the MTO, MTS according to DDMRP and MTS according to coverage, under nine scenarios where demand and production sources were varied. Operating costs results to MTO methodology are better, with 48% decrease compared to MTS according to DDMRP, and 28% compared to MTS according to coverage. In terms of service level and robustness, the MTS methodology according to coverage has a slight advantage with 99.62%, compared to MTO and MTS according to DDMRP, with 99.49% and 98.71% respectively.

Keywords
SCRM, MTS, MTO, shelf life

1. Introduction
In recent decades, there has been evidence of alterations due to climate change effects, high pollution volumes and progressive biodiversity loss, as reported by the World Economic Forum (WEF, 2020). This constrains the production, storage and transportation processes in supply chains, increasing the possibility of generating differences between planning and result of all their activities. Organizations dedicated to food handling and transformation face risk factors generated by the material perishability that requires reconfiguring their processes according to the product requirements to increase the material shelf life and this increases the company's operational costs due to the waste

generated in the processes. The Food and Agriculture Organization of the United Nations (FAO) defines food loss and waste as the decrease in quantity or quality of food due to decisions made along the supply chain (SC) (FAO 2019). Losses are generated by failures in the processes of supply, transformation and distribution to retailers. Waste is generated by retailers' inventory management or demand planning errors. FAO (2019) estimates that in 2016, 12% of meat and animal-derived products were lost, creating the challenge of efficiently managing inventories throughout the SC.

Inventory management and control consist of two phases: the first phase determines the place where the inventory should be located and the second phase defines the product quantities to be kept in stock. There are methodologies such as Demand Driven MRP (DDMRP) that support inventory management in CS (Institute 2019). Part of this methodology is based on principles developed in the Make to Order (MTO) and Make to Stock (MTS) methods, which guides production or logistics operations according to customer orders or inventory status, respectively.

The scientific community has developed the term Supply Chain Risk Management (SCRM) and has had a growing interest recently, due to events that have occurred worldwide, such as the pandemic generated by COVID-19, which since 2019 have affected the global economy (Smialek and Tankersley 2020), (Goodman 2020). SCRM is defined in three stages: identify, measure and mitigate risks. Few SCRM papers include valued scenarios to compare the consequences when a risk materializes and the costs generated by the actions taken to mitigate it. This work configures the raw material supply with short shelf life in a hybrid MTS/MTO production scenario, minimizing cost and operational risk by comparing the behavior of SC with the mentioned characteristics. To achieve the general objective of this work, the necessary criteria were defined to position inventory in SC with operational risks associated with its shelf life. Based on the configuration between the MTO and MTS scenarios, a guide is generated to determine the supply chain order penetration point (OPP). The case study is based on a deboning plant in the meat industry and its decisions associated with freezing or refrigeration of product in the inventory. The SC is simulated using System Dynamics, generating a model that allows relating and analyzing different variables that can minimize risk and operational cost. Finally, three configurations were simulated: MTO, MTS according to DDMRP and MTS according to inventory coverage, compared with the sensitivity analysis.

The document includes a literature review, based on the terms SCRM, MTO, MTS and shelf life. Subsequently, the methodological stages are presented, with activities that were performed. The next chapter details data collection and processing. Finally, the numerical and graphical results are shown, with the conclusions.

2. Literature Review

The scientific community initiated the identification of risk as a field of research in food SC (Rajurkar and Jain 2011), developing work associated with key factors in the location of inventory in its links. (Kittipanya et al. 2011), (Cai et al. 2013), (Henry and Wernz 2014), (Duong and Paché 2016). Studies have been performed on the distribution of bargaining power and its impact on prices and quantities. (Li et al. 2014), (Madichie and Yamoah 2017). The first sources of risk identified are associated with selection (Galo et al. 2018) and supplier evaluation (Roghanian, et al. 2014), (Pourmassahian et al. 2014), (Sun 2015), (Azadnia et al. 2015). To determine this selection, qualitative or semi-quantitative tools were initially developed, such as the Analytic Hierarchy Process (AHP), Fuzzy Logic (FL) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). Subsequently, the CS risks are analyzed including variables associated with the demand (Juárez et al. 2016), delivery times, costs and prices, development of traceability in food SC (Rincón et al. 2017), sustainable SC management (Guevara and Guillermo, 2018) and the development of methodologies for classifying and diagnosing a SC (Calderón, et al. 2017). Innovation occurs by linking risks in the composition of the objective function of optimization models that seek to minimize costs or maximize profits. (Das and Nayak 2017), (Bai and Liu 2016), (Grillo et al. 2016), and in this case there are methodologies such as: Game Theory (GT), Linear Programming (LP), Mixed Integer Linear Programming (MILP), Goal Programming (GP), Fuzzy Optimization and Simulation.

In the literature associated with SCRM, in shelf-life constrained production environments, the constant appearance of performance measures are observed (See Figure 1). Especially in the food industry, indicators such as service level and productivity have been established. (Amorim et al. 2013), recently complemented by measures such as Complexity, Flexibility, Robustness, Vulnerability and Resilience. (Dittfeld et al. 2018), (Kulkarni and Francas, 2018), (Behzadi et al. 2018). Even with these indicators, there is a deficit in the study of performance measures associated with CS of perishable products. (Kashav et al. 2018).

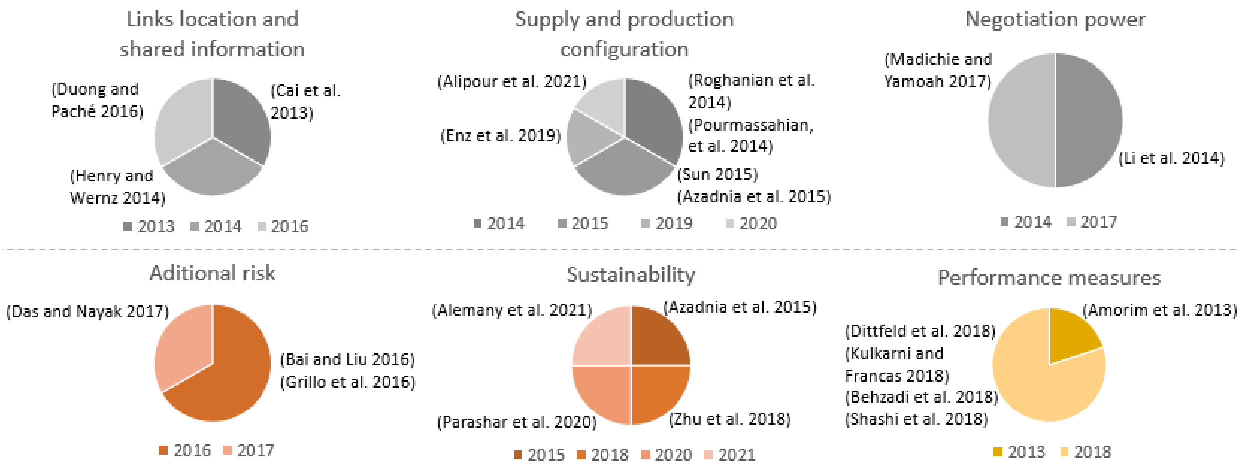

Figure 1. Relationship between topics developed and publication years of documents.

The development of research associated with these topics has been growing consistently over the last decade; in fact, it was only in 2013 the first publications were presented, focusing on topics such as the location of links and shared information, and performance measures for SCs. Recently, sustainability has made its presence felt, something that may indicate that it will position itself as a strong route for future research. SC modeling is performed through simulation and optimization (Ge et al. 2015). As for the simulation methods that can be used to model risk, system dynamics is scarce and is proposed as a future research, due to its advantages in understanding the system holistically and the interrelationship between its variables (Behzadi et al. 2018).

3. Methods

The methodological phases, along with the activities and tools used to meet the proposed objectives are presented in Figure 2. These phases are based on the SCRM fundamentals, complemented by an initial CS characterization phase and a final phase where the results are analyzed and sensitivity analyses are performed. Through a literature review, complemented with semi-structured surveys, the aim is to identify the inventory positioning criteria, with the objective of understanding how decisions are made in a CS with respect to its inventory management policies. To detail the variables that are considered. With the objective to understand the SC's complexity level, the literature is searched for articles that contain elements associated with the configuration of supply chains, such as the definition of suppliers, inventory management policies, with emphasis on the definition of the sites where they would be located, among others, which would lead to dimensioning the complexity of the process (Luo et al. 2017), (Amorim et al. 2013), (Dittfeld et al. 2018).

For risk identification, the first SCRM phase, qualitative methodologies are widely used and their effectiveness is recognized by the joint construction they propose and the variety of tools available. (Chapman 1998). Specifically, the methods that allow quantifying qualitative perspectives, built by teamwork or interviews, are even more important. (Markmann et al. 2013). For this reason, a semi-structured survey is developed, with the objective to complement the risks identified in the literature and prioritize them according to the occurrence probability and severity. For the survey application, experts should be selected, considering characteristics such as their role and impact on tactical and strategic decisions. With the objective of providing a holistic view of operational risks, functional areas such as Logistics, Production, Quality, Planning, Procurement, Purchasing and Human Resources should be included. Due to the restrictions generated by quarantine, the survey was virtually applied and it was easier to expand participants' list.

The Risk Measurement phase is divided into two sub-stages: Risk measurement through CS modeling, and model validation and verification. In the first sub-phase is developed a simulation model using system dynamics, with the objective of understanding the interrelationship between the variables linked to the materials flow control with a short shelf life. The MTO/MTS strategies that influence the decisions associated with the OPP are modeled, where the supply push flow and the pull flow corresponding to real needs of the analyzed process converge. The purpose of this model is to have a tool that allows configuring the operations that have associated risks that can materialize and generate an increase in operating cost. In the model validation and verification sub-phase, the methodology proposed by Forrester and Senge (1980) is used as a guide, which is made in two steps: model structure validation and behavioral validation. For the structure, the evaluation of the model architecture, parameter validity verification, extreme conditions, model limits and dimensional consistency are carried out. Since it is a real case, behavior validation is made with the experts' support, who review the logics of exercise and the results obtained consistency. According to Jaén (2014) these tests support the developments in system dynamics model validation found in the literature, even considering that new methodologies such as LEEA have been developed, used by Gonçalves (2003), Gonçalves et al. (2000), and Kampamnn (1996), but do not question model's real validity.

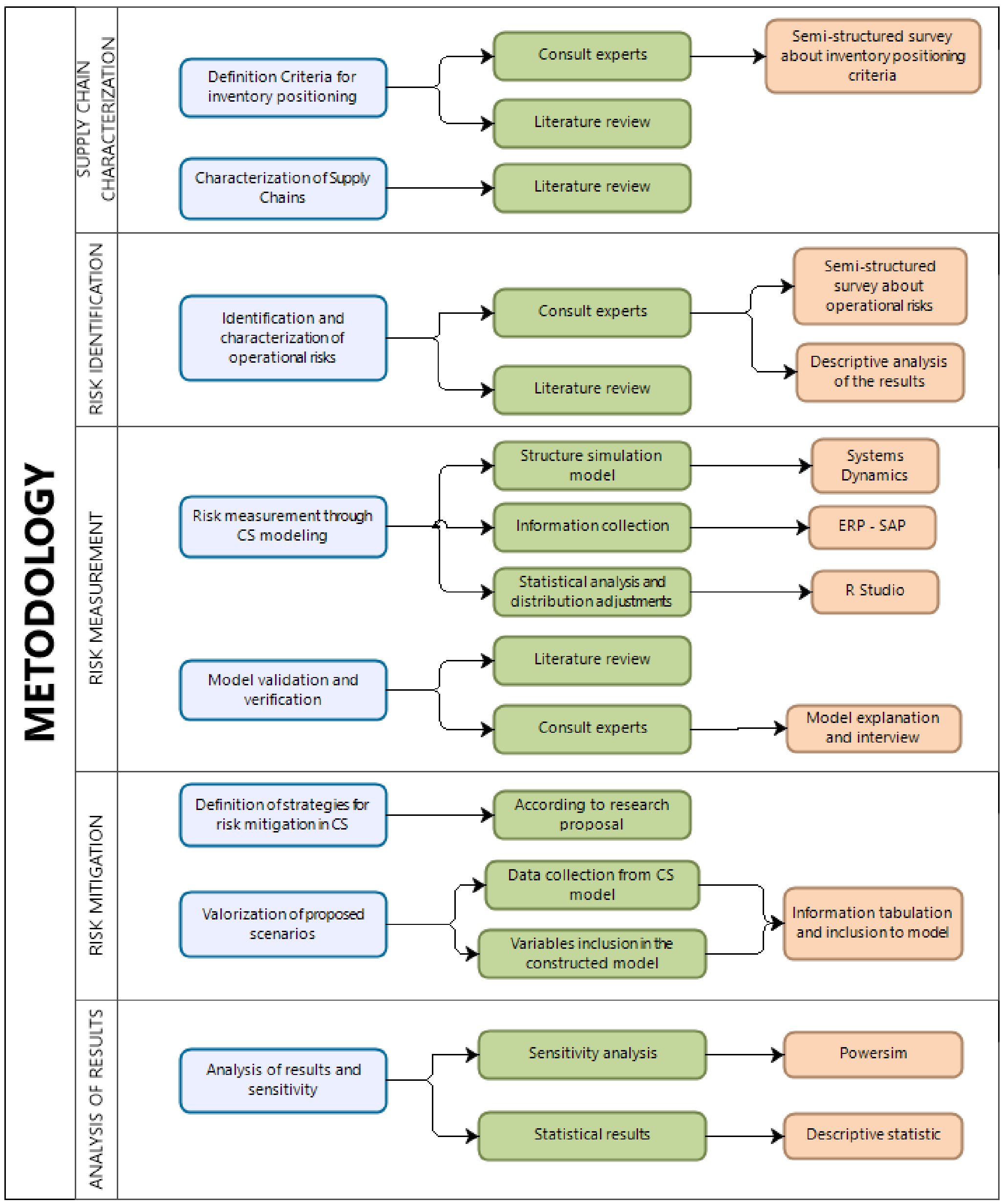

Figure 2. Methodological phases of research and relationship with used tools.

For risk mitigation, the third SCRM phase, the objective is to propose actions to improve the supply chain performance in the event of the possible materialization of the risks previously identified. The results obtained under the three scenarios are compared. The first scenario is MTO, where boning orders are created according to the real needs of the production plants. The second scenario is MTS according to DDMRP, where deboning orders are created according to the buffers located in the processing plants. The third scenario is MTS according to coverage, where a quantity of inventory is raised according to the average daily demand, multiplied by a defined days to cover the needs. Each scenario is evaluated in eight instances different from its baseline. In three of them demand is modified, in three others production is modified, and in the last two production is suspended with two different frequencies. As a measure of comparison, costs are used as usual indicators in a CS, such as service level, complemented with Robustness, associate to risk. Whit these results a sensitivity analysis is developed with the objective of understanding the dependence level that exists between output variables, such as expiration and stock out, and the parameters associated with demand, production and the frequency of interruptions that can be generated in the process. These analyses are carried out by means of the Powersim tool, where the system dynamics simulation model was developed.

4. Data Collection

Information was collected through Enterprise Resource Planning (ERP), from which consumption and production during March, April and May 2019 were obtained. Consumption refers to the amount of meat raw material (MRM) required by the production plant. Production is taken from the MRM generation, in refrigerated and frozen state, in deboning plant. Analysis was prioritized on one of the twelve MRM, bearing in mind the physical characteristics, sources of supply, role in planning and use of the raw material in the finished product. The assumptions were generated by the process real conditions. Table 1 shows the assumptions and decision variables and their description.

Table 1. Descripción de supuestos y variables de decisión.

Description	Type	Explanation
Shelf life	Assumptions	Frozen material: one year. Refrigerated material: six or five days.
Transportation time	Assumptions	Transfers in same city: one day. Other city: two days.
MRM preparation times	Assumptions	For all facilities, MRM preparation is performed one day before use.
Transport conditions	Assumptions	All material can be transported in the same vehicle.
Order creation in production plant	Assumptions	Daily frequency of order creation. Until 14:00 hours. For MTO with necessary anticipation that the boning process lead time requires.
Order creation in boning plant	Assumptions	Daily frequency of order creation. Until 17:00 hours. Considering the animals to be boned and production plant orders.
Production quantity in refrigerated state	Decision variables	The lowest value between plants request and disponibility.
Refrigerated inventory	Decision variables	Each level represents the refrigerated inventory that has the shelf life days declared.
Frozen inventory	Decision variables	All the accumulated MRM frozen inventory is represented on the same level.

The parameters linked to the model have great relevance in the three scenarios modeled, especially in MTS according to DDMRP, since this methodology is based on several elements that must be determined before the definition of the quantity to be replenished (see Table 2).

Table 2. List of parameters associated with the simulation model.

Name	Category	Source	Value	Units
Defrost Cost	Costs	Defrosting process	155	$ / kg
Refrigerated Inventory Cost	Costs	External company quote	7	$ / (kg * day)
Frozen Inventory Cost	Costs	External company quote	25	$ / (kg * day)
Expiration Cost	Costs	ERP SAP - Financial Module	9435	$ / kg
Stock out Cost	Costs	Sourcing process	5450	$ / kg

Lead Time	DDMRP	Sourcing process	4	Day
Frequency	DDMRP	Sourcing process	1	Day
MOQ	DDMRP	Sourcing process	500	Kg
LT and Variability Factor	DDMRP	Sourcing process	0.3	-
Days ADU	DDMRP	Sourcing process	15	Day
Days inventory	Coverage	Sourcing process	5	Day

5. Results and Discussion

Defined system dynamics as the ideal modeling method to fulfill the objective of the work, the relationship between the main components of the dynamic hypothesis must be understood (See figure 3).

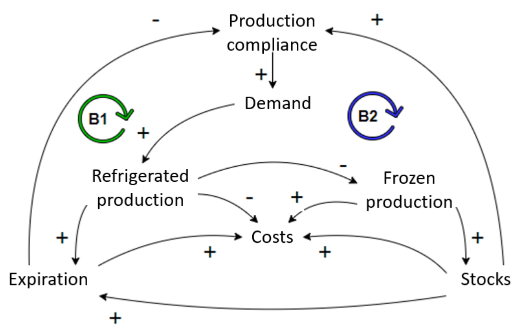

Figure 3. Principal components of dynamic hypothesis.

In the statement of the dynamic hypothesis, two dynamics are illustrated that represent the behavior of the variables associated with the supply of raw materials. The balance cycle B1 is associated with the increase in refrigerated production, which directly affects the costs generated at the expiration dates of refrigerated units. The balance cycle B2 refers to an increase in frozen production that directly affects costs caused by maintaining a frozen inventory. Compliance in production planning (production compliance) triggers an increase in the units demanded (demand), which leads directly to requesting a greater quantity of refrigerated raw material (refrigerated production), generating a decrease in the production of frozen raw material (Frozen production). However, an increase in refrigerated production increases refrigerated units expiration (expirations), which can put production compliance at risk. However, if the frozen production is increased, the costs and the amount of inventory (inventories) will increase, which can guarantee the fulfillment of the production, but can generate a greater risk of expiration if it is not possible to consume before the end of its shelf life.

5.1 Numerical Results

Based on the methodology described previously, the numerical results are presented. In the first phase, inventory positioning criteria were prioritized (see Table 3). In the first and second positions are elements related to lead time, a factor that DDMRP promises to reduce. As new, the prioritization are the last two criteria, associated with the critical operation protection, related to buffer objective in Theory of Constraints (TOC) (Rand 2000), and the customer's tolerance time, which a priori can be classified as a fundamental constraint for the definition of inventory positioning.

Table 3. Prioritization of inventory positioning criteria.

Inventory positioning criteria	Priorization
Customer tolerance time	6
Market potential lead time	1
Sales order horizon	4
External variability	3
Critical Operation Protection	5

Inventory leverage and flexibility	2

Risk identification is presented in table 4 where they are classified according to the area affected by the materialization of the risk. Risk prioritization was done through semi-structured surveys applied to quality, logistics, production and planning employees. With greater relevance appears the loss of the cold chain, which, like accidents or problems on public roads, lead to the material loss.

Table 4. Result of the identification of risks in the SC. Top five of the best rated.

Classification	Risk	Qualification
Productive process	Loss of the cold chain	1363
Politics, Environment and Social	Affection by information disseminated in the mass media	1242
Supplier	Uncertainty in the costs of acquisition of PM and supplies	1200
Productive process	Uncertainty and/or high variation in the programmed quantities	1120
Demand	High variability in the quantities demanded	1080

With P-value 0.8592, the Weibull distribution is defined as a representation of the behavior of demand and production. The scale parameter is 9920.268 and the shape parameter is 6.215. These parameters are modified to generate six of the eight instances of the scenarios described in the methodology. It was concluded in all instances that the configuration of operations according to production or customer orders (MTO) reduces costs. That is, in terms of inventory positioning, it is not convenient to configure a decoupling in production plants, when the shelf life of the product is 5 to 6 days (See table 5).

Table 5. Variation of results compared with MTO and Baseline

	MTO as a basis			Baseline as a basis		
Parameter variation in scenario	MTO	MTS/ DDMRP	MTS/ Coverage	MTO	MTS/ DDMRP	MTS/ Coverage
Without Variations	0%	48%	28%	0%	0%	0%
Demand variation (20%)	0%	49%	9%	8%	8%	-9%
Demand variation (60%)	0%	44%	22%	17%	14%	12%
Demand variation (100%)	0%	51%	32%	32%	35%	36%
Production variation (20%)	0%	58%	35%	-8%	-2%	-3%
Production variation (60%)	0%	56%	22%	-8%	-3%	-12%
Production variation (100%)	0%	54%	1%	-5%	-1%	-25%
Material loss (1 / mes)	0%	31%	21%	57%	40%	48%
Material loss (2 / mes)	0%	9%	3%	177%	105%	123%

Changes in demand when the scenario corresponds to a simulation with parameters that do not show variations generate a greater impact on the cost. Variations generate expiration in the MRM, causing the highest cost. The variation in production impacts the operating cost to a lesser extent, due to the cost assigned to the non-compliance with the demand.

5.2 Graphical Results

When analyzing the interaction between variables, it is vital to understand the level of sensitivity that exists between them. We took the MRM supply interruption parameter, since it is related to the risk with the highest rating (View Figure 4). With small variations in this parameter, no changes in expiration are observed in the MTO scenario, but there is high sensitivity in the stock out. In both MTS scenarios, sensitivity is high in both stock out and expiration.

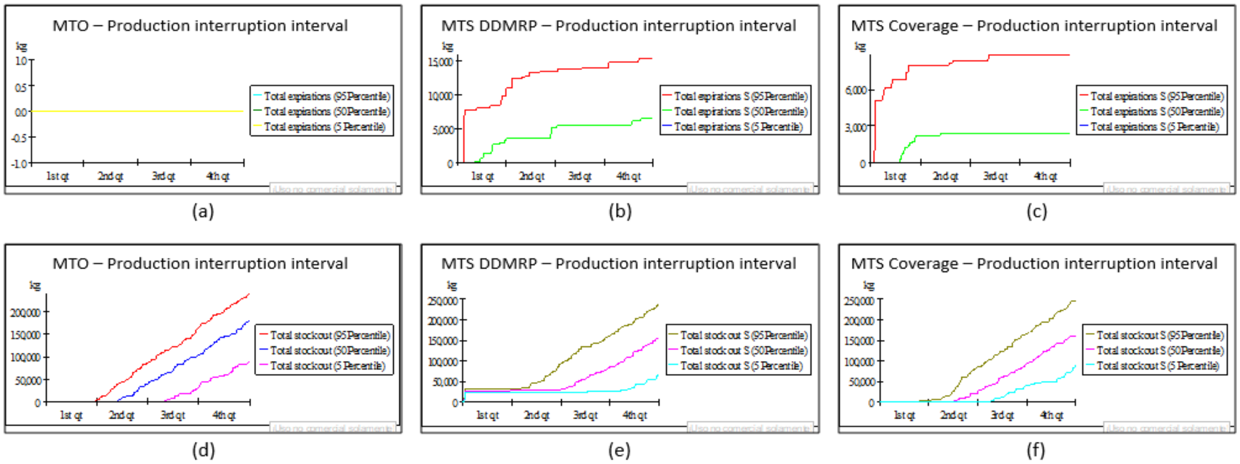

Figure 4. Sensitivity analysis in MTO, MTS DDMRP and MTS Coverage scenarios.

5.3 Proposed Improvements

Based on the numerical and graphical results, it is suggested to define MTO as the methodology by which the flow of materials is controlled along the supply chains in which their materials have a strong restriction of shelf life. This makes it possible to control the impact of the materialization of the risk, achieving greater robustness, by eliminating the sensitivity of MRM expiration to variations in demand, production and loss of product.

5.4 Validation

Each part of the simulation model by system dynamics is associated with the decision made in the SC when receiving a demand from the production plant, either the creation of an order or the need to replenish the inventory. Figure 5 shows the logic by which the MRM state is defined. The minimum value is produced between production and the needs of the production plants.

If the quantity produced is greater than that needed, the initial difference is the freezing flow (See figure 6 (a)), where it is stored until it must be defrosted for later consumption. When this happens, the flow of refrigerated material is activated, coming from this process (See figure 6 (c)), which has a lead time of one day before being available. The refrigerated material begins a logistical transfer that consumes 40% of its shelf life, therefore it becomes available with only three possible days for consumption (See figure 6 (b)).

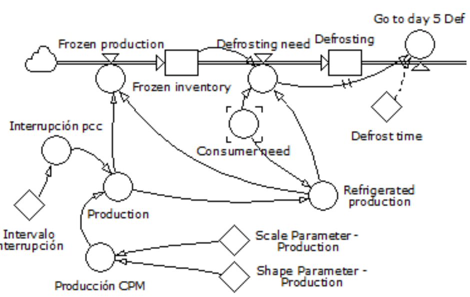

Figure 5. Definition of production state

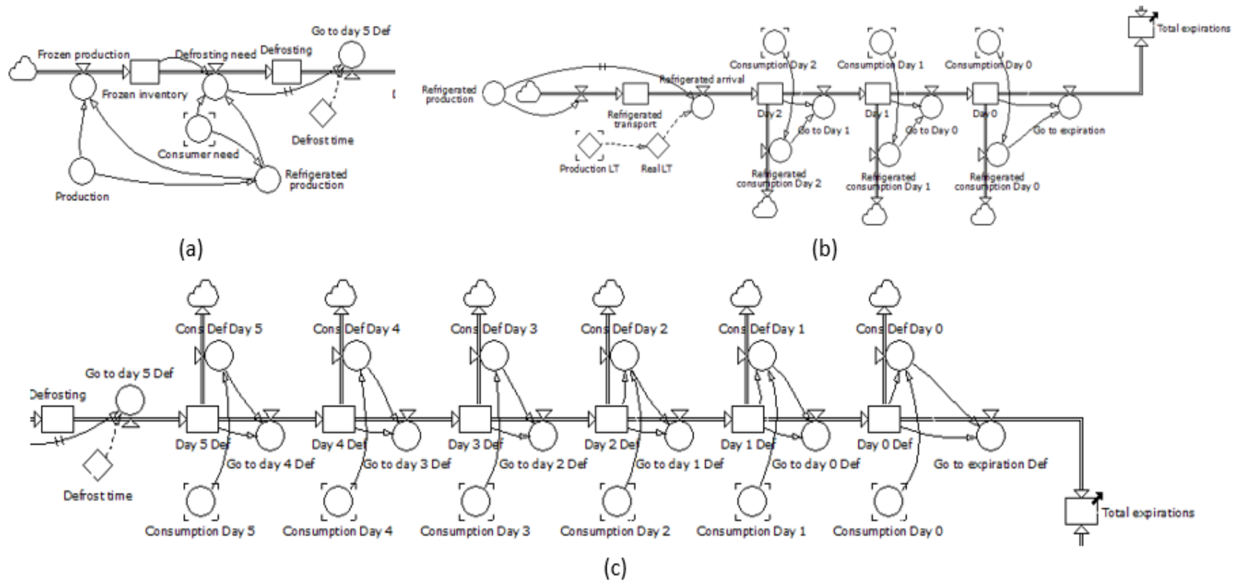

Figure 6. Cooled and frozen material flows

To start the construction of the cost structure, the inventory must be totalized in all the nodes of the SC. The frozen inventory is seen in Figure 6 (a). The refrigerated inventory is made up of the sum of the inventory in each day of shelf life. There are four cost structures. First, for the cost of inventory, the refrigerated and frozen quantities are added, multiplied by their unit daily maintenance cost (See figure 7 (a)). Second, the stock out are totaled for each simulation step and multiplied by a unit cost, associated with a MRM replacement (See figure 7 (b)). Third, for the expiration cost, the total of products that were not consumed during their shelf life are taken and multiplied by their manufacturing cost (See figure 7 (c)). Finally, the defrosting cost is activated when the refrigerated flow cannot meet the demand, in this case this amount is multiplied by a cost associated with this process (See figure 7 (d)).

The need for consumption is obtained through the generation of a random variable, according to the parameters established in the previous statistical analysis. In the MTO scenario, the time in which this need must be fulfilled depends on the operation times, for this reason a delay is linked in this process. For MTS scenarios, the need for consumption must be met immediately, depending on the amount of inventory that is available (See figure (8)).

To create the buffer according to the DDMRP methodology, four stripes must be configured. Green is defined as the maximum value between the minimum order quantity (MOQ), average daily consumption (ADU) x frequency and ADU x LT x LT factor. The yellow band is equal to the multiplication between ADU x LT. The lower red band is equal to the yellow band multiplied by the LT factor. Finally, the upper red band is the multiplication between the lower red band and the variability factor. The buffer is made up of the sum of all of them (See figure 9 (a)). The material quantity to be produced is determined according to the lack of this sum, minus the inventory and existing transits. The ADU determination was configured according to the sales average daily in the last two weeks (See figure 9 (b)). Finally, for the MTS scenario according to coverage, the demand is determined from a buffer configuration, such as the multiplication between ADU and coverage days to have versus the on-site and transit inventory (See figure 9 (c)).

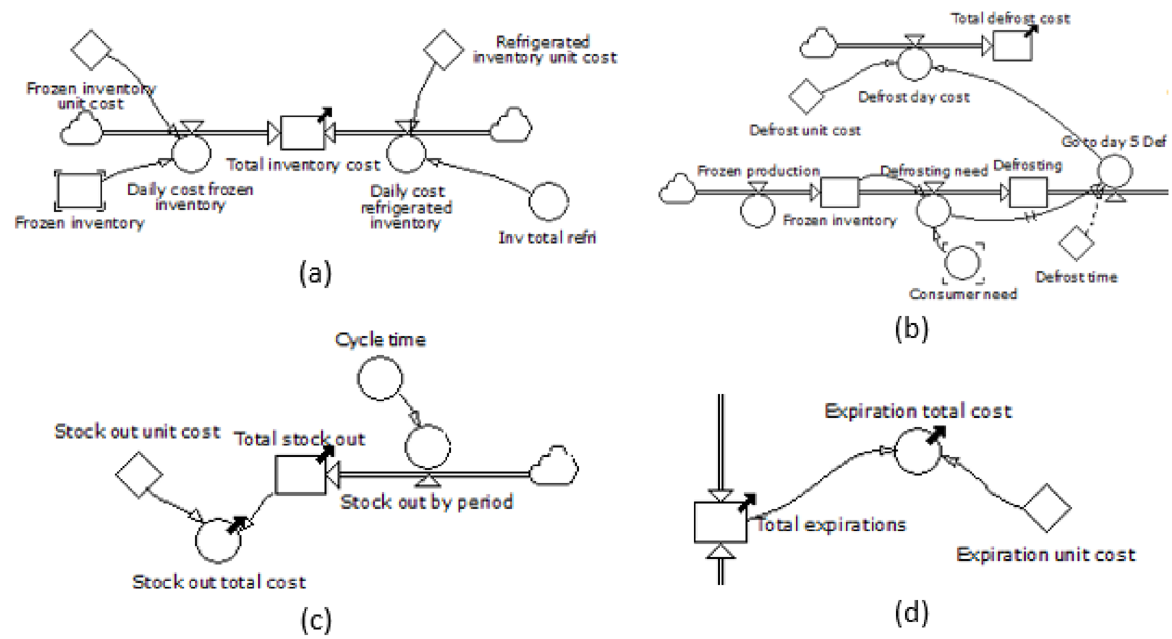

Figure 7. Cost structures.

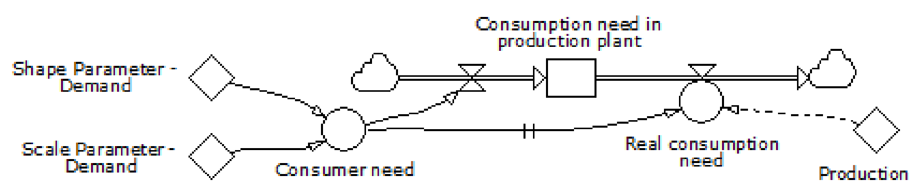

Figure 8. Reasoning of MRM consumption.

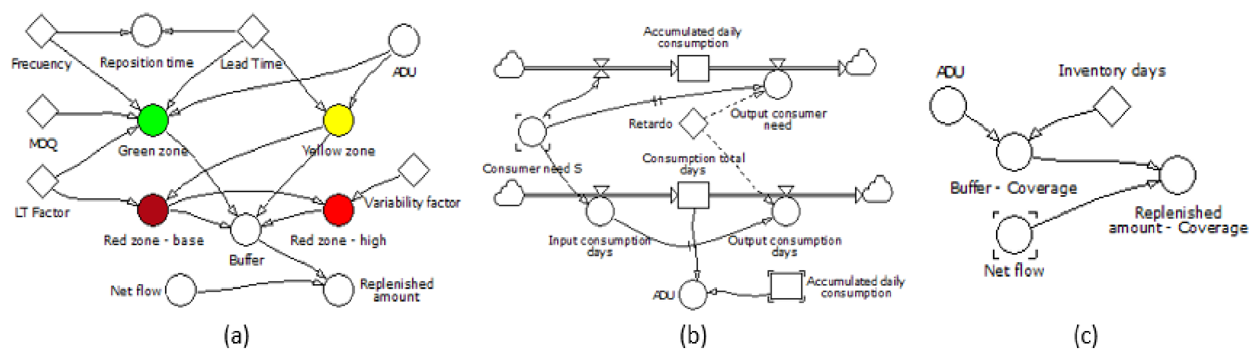

Figure 9. Buffer and ADU configuration according to MTS.

The linking of the parameters to the model was carried out through the collection of information on the operations in the CS used as an example, complemented by quotes from companies that provide logistics services (See table 2). For the extreme conditions validation we take the frozen inventory as a calibration measure. When demand for the MRM increased, the inventory ended the year without stock. In contrast, when production increased, a high expirations amount was generated and inventory levels grew significantly.

To know if the level of detail with which the structure was developed provides valid results, the limits of the model must be evaluated. In this case, the process knowledge was linked from its development, with which the simulation steps and details of the material movement were defined. The definition of the modeling detail was to be provided by the deboning plant scheduling periodicity, which is made daily basis. Additionally, MRM transfers and production orders in the processing plants are also created daily. Dimensional consistency allows the conservation of matter in the system (Sterman 2000), (Mohapatra et al. 1994), which can be seen in the parameter analysis, the model structure and the results shown in the previous chapters. Finally, the validation of the behavior was carried out by means of the appreciation of the experts, to whom the logic of the exercise and the results delivered were explained, obtaining a favorable response to the reality representativeness.

6. Conclusions

Inventory positioning criteria must be taken into account when setting up a SC. This work shows the importance of including the characteristics of the products that are transformed throughout the operations in the SC. The shelf life creates an important restriction in this definition. The loss of the cold chain, impact by information disseminated in the mass media and uncertainty in the acquisition costs of RM and supplies are recognized as the most relevant risks in operations. Its materialization generates product loss, greater variation in demand or supply. Modeling the SC with a shelf life restriction in your products, allows you to link the largest number of process variables and evaluate the cost and risk of operations, and the appropriate configuration to manage inventories in each link. In this particular case, where the MRM has five days of shelf life, of which two are consumed in logistics operations, it is recommended to activate the productive nodes according to the MTO methodology. When inventory positioning is generated, either under DDMRP or under coverage, total costs can increase by 48% and 28% respectively. The costs of operations are highly sensitive to few changes in demand or production. Controlling the product flow using MTO, throughout a SC with a strong shelf life restriction, increases its robustness, by controlling the risks of expiration of its raw material. This without significantly affects the service level, which stands at 99.48%. Research on new performance measures for this type of SC is considered future work, accompanied by the need to model new instances, such as the coordination of activities when there are non-working days that consume the shelf life of the product. Additionally, the complete link of the financial chapter, by including the generated income and indicators such as EBITDA margin or ROIC, can provide a greater understanding of the full impact on the SC.

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