UNIVERSIDAD DEL NORTE

Assessment of joint inventory replenishment: A Cooperative Games approach

Thesis manuscript for the title of Doctor of Industrial Engineering

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Departamento de Ingeniería Industrial
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Barranquilla

2020

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July, 2020

AUTHOR NOTES

This manuscript was fortuitously written at the times of the COVID-19; a tough challenge that we almost self-predestined to undertake, a time of deep reflection for humanity, which in the catharsis began to find the foundations for a new beginning. A special challenge for Latin America, which in the second decade of the 21st century began entrenched in the fight against persistent social inequality, in the abyss of violence and facing the worldwide environmental crisis. It is possible to think these days that empathy is an inexorable requirement for the transcendence of Aristotle's -*political animals*- and of our civic essence. This thesis is well framed for this time, where even in the aggressive business dynamics it does well *to collude* for the common good. The *collaboration* fits well these days; center and heart of this work, which reflects my deepest wishes to contribute to generate equity and help safeguard the environment.

My greatest thanks without a doubt is to GOD; constantly encouraging and creator of the subtle opportunities that allowed me to gather the elements that materialized what is today a finished work and the beginning of new paths for my life.

Special gratitude to my tutors, Dr. René Amaya and Dr. Jairo Montoya, who with honesty, integrity, mastery, and generosity allowed me to have the opportunity to learn the noble work of doing research.

Thanks to my family for the inspired courage, and a special chapter for my second family; my friends in Barranquilla: Nico, Ruro, R. Yie, Andrés, Cris, Robert, Adri, Caro, Male, and Dayni, who were invaluable moral support, countless pleasant moments of joy, afternoons and nights of music and drinks.

___*Español*

Este manuscrito fue fortuitamente escrito en tiempos del COVID-19; un duro desafío que casi auto-predestinamos emprender, época de profunda reflexión para la humanidad, que en la catarsis empezó a encontrar los fundamentos para un nuevo comienzo. Especial reto para Latinoamérica, que en la segunda década del Siglo XXI empezó atrincherada en la lucha en contra de una persistente inequidad social, en el abismo de la violencia y en un abrumador daño medioambiental. Cabe pensar por estos días, que la empatía es inexorable requisito para la trascendencia de los -*animales políticos*- de Aristóteles y de nuestra esencia cívica. Esta tesis bien enmarca para esta época, donde incluso en la dinámica competitiva empresarial sin cuartel hace bien *coludir* por el bien común. Bien cohesiona la *colaboración* por estos días; centro y corazón de este trabajo, quien refleja mis más profundos deseos de contribuir a generar equidad y ayudar a salvaguardar el medio ambiente.

Mi más grande agradecimiento sin duda es para DIOS; constante alentador y artífice de las sutiles oportunidades que me permitieron reunir los elementos que materializaron lo que es hoy un trabajo terminado, y el comienzo de nuevos caminos para mi vida.

Especial gratitud a mis tutores, Dr. René Amaya y Dr. Jairo Montoya, quienes en honesta labor, entereza, maestría y generosidad dispusieron brindarme la oportunidad de aprender la noble labor de *hacer* investigación.

Gracias a mi familia por el coraje inspirado, y un especial capítulo para mi segunda familia, mis amistades en Barranquilla: Nico, Ruro, R. Yie, Andrés, Cris, Robert, Adri, Caro, Male y Dayni, quienes fueron invaluable soporte moral, incontables gratos ratos de alegría, tardes y noches de música y copas.

DEDICATION

Homage is everything is for you, who has given me the opportunity to know the purest and most genuine feeling of love. To you, who with an always hopeful voice and rosary in hand have turned anguish into laughter. Receive this sincere tribute loved Grandmother Hilda de Otero.

To my brothers: Sergio, Cristian, Andrés G, Lina, Estefanía and Valeria, whom I encourage to work frankly for their dreams, with the certainty that perseverance and temperance are destined for success.

___*Español*

El homenaje es todo es para ti, quien me ha dado la oportunidad de conocer el más puro y genuino sentimiento de *amor*. A ti, que con voz siempre esperanzadora y rosario en mano has convertido las angustias en risas. Recibe este sincero homenaje amada abuela *Hilda de Otero.*

A mis hermanos: Sergio, Cristian, Andrés G, Lina, Estefanía y Valeria a quienes aliento a trabajar en franca lid por sus sueños, con la certeza de que la constancia y templanza están destinadas al éxito.

ABSTRACT

This research deals with the design of a logistics strategy with a collaborative approach between non-competing companies, who through joint coordination of the replenishment of their inventories reduce their costs thanks to the exploitation of economies of scale. The proposal is based on the hypothesis that such an inter-business association allows reducing the individual costs inherent in the inventory when capacity limitations and stochastic demand are faced.

Multi-item replenishment is feasible in the presence of high fixed costs for ordering and holding inventories, thus the total unit cost for inventory management might be reduced in contrast to the replenishment of a single item. This situation is recognized in the literature as the joint replenishment problem (JRP). The JRP is based, however, on contentious assumptions, such as to consider demand as a deterministic variable, to neglect lead times, to assume unlimited storage and transport capacities, among others. Consequently, it is proposed a model that the author named the Stochastic Collaborative Joint Replenishment Problem (S-CJRP), as an extension of the JRP, for multiple buyers and suppliers, restricted by capacity and stochastic demand. On another hand, the operation of the collaborative agreements has the purpose of generating certain surpluses or benefits for the players, but the contributions of the players could be asymmetric. This situation supposes an important challenge when it comes to sharing the common benefits since a potential nonconformity could generate imbalances that would harm the formation of the agreements. Therefore, the use of Collaborative Game Theory's principles and techniques is proposed to assign such benefits.

The overall achievement of this research is the development of an eclectic procedure based on heuristics and meta-heuristics that successively integrates techniques of optimization and Game Theory under stochastic demand, capacity constraints, multiple buyers, and for a fixed coalition of non-competing companies. The present research aims for increasing practical elements into the inventory replenishment problem and to assess to what extent collaboration in inventory replenishment and logistics resources sharing might reduce the inventory costs. It includes as a study the logistics activity features of Colombia for illustration, but it may be extended to almost any other latitude. Furthermore, for a practical instance developed in California, U.S., the work shows the potential of JRP models to help decision-makers to better understand the impacts of fleet renewal and inventory replenishment decisions over the cost and CO_2 emissions. For this purpose, a multi-objective extension of the JRP is introduced. In overall, results showed that the proposed model could be a viable alternative to reduce logistics costs (around 31% less according to the tested scenarios) and demonstrated how the model can be a financially preferred alternative than individual investments to leverage resources capacity expansions. In addition, it is shown that the strategy is robust and/or desirable on the face of unexpected changes in lead times and replenishment costs. Directions are as well provided so as to improve understanding on how to exploit the benefits of the strategy, and on how to anticipate agreements to allow for the arrival of new players. It is also provided a validated cost structure that enables the estimation of the S-CJRP model and related extensions in the practice.

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CONTENT

LIST OF FIGURES

LIST OF TABLES

PRELIMINARY CONCEPTS

Player: Refers to the participants of a game (i.e., an agreement for the purposes of this work), whether cooperative or non-cooperative, who compete jointly or antagonistically for a benefit. In this document, it refers to participants in a coalition.

Coalition: In Game Theory, refers to the set of players who join or collude in order to take advantage of a situation or market, enhancing their individual skills with those of other players. This research refers to the companies or buyers that must be associated to decrease the cost of inventory management.

Heuristic: Rules or step-by-step procedures that generate solutions to particular problems in relatively short computational times, when the classic or exact methods are non-convenient for time or fail to find the optimal solution. Although in some instances of a problem the optimal could be found, it cannot always be guaranteed. Heuristics could be considered as shortcut techniques that sacrifice optimality, integrity, or precision in exchange for speed.

Meta-heuristic: It is an approximate, top-level solution method for solving general computational problems, using parameters over generic and abstract procedures in a way that is expected to be efficient. Meta-heuristics are generally applied to problems that do not have a specific algorithm or heuristic that gives a satisfactory solution; or when it is not possible to implement a method that guarantees the optimum. Most meta-heuristics aim to solve combinatorial optimization problems, but of course, they can be applied to any problem that can be reformulated in heuristic terms.

Optimization: Optimizing consists of maximizing or minimizing a function by systematically choosing input values within a feasible set of values and computing the value in a function of interest. In general, optimization consists of finding the "best values" or optimal value of some objective function given a defined domain. Although strictly minimizing or maximizing implies guaranteeing an optimal value, the use of these terms can often be found in the literature to indicate that an attempt is made to find the best possible value according to the case, it could imply the use of a heuristic or meta-heuristic procedures.

NP-Hard problem: Informally it is the set of problems that are at least as difficult to solve as the most difficult problems in the NP class (those that can be verified in polynomial time). In an illustrative way, a problem S is NP-Hard when each problem B belonging to NP can be reduced in polynomial time to S; that is, assuming that we find a solution for S, we can use that solution of S to solve B in polynomial time. As a consequence, finding a polynomial algorithm to solve any NP-Hard problem would generate polynomial algorithms for all NP problems, although it is suspected that there are no polynomial-time algorithms for NP-Hard problems, this has not yet been proven.

INTRODUCTION

The market intense dynamics and financial pressures imperatively demand the satisfaction of customer demand at a lessening cost. Under this scenario, companies have implemented different strategies to improve supply chain resilience, among which collaboration between companies appears as a viable alternative. Collaboration allows the generation of win-win situations that could become competitive advantages, which individually could not be achieved (Simatupang & Sridharan, 2005). Collaborative/Cooperative practices date back to the 1990's with the implementation of strategies that sought synchronization between echelons in the same supply chain to reduce the bullwhip effect, a known over-cost generator due to the lack of coordination (Småros, Lehtonen, Appelqvist, & Holmström, 2003). Later, strategies appeared that sought integration between echelons in companies belonging to different supply chains that might or might not be antagonists (Barratt, 2007; Naesens, Gelders, & Pintelon, 2007). In general these strategies demonstrate benefits such as: cost reduction, better service levels, better inventory control, etc. (Holweg, Disney, Holmström, & Småros, 2005a).

The main objective of an inventory model is nothing more than satisfying demand at minimum cost. These models are mostly made up of two clearly differentiated cost elements; the cost of ordering and the cost of holding. In themselves, these could be subdivided into as many elements as there are activities, inherent to the management and execution of an inventory policy (Silver, Pyke, & Peterson, 1998). Due to the existence of costs of a fixed nature, it makes sense to schedule joint replenishments; since the massive aggregation of multiple items would allow the exploitation of economies of scale (Silver, 1974). Increasing the lot size to reach scale is convenient, but often impossible for companies with limited capacities, therefore generating a significant opportunity cost that could desirably be exploited.

This thesis explores collaboration in inventory replenishment as an alternative to reduce logistics costs through the joint exploitation of economies of scale. It proposes the design of a collaborative strategy that involves the integration of processes of different supply chains, in order to maximize the use of logistics resources and exploit fixed cost, in a way that the companies individually would not reach. The strategy is to coordinate the inventory replenishment of multiple non-competing companies, essentially importers that face high fixed costs inherent in the international replenishment process. In particular, these companies face capacity limitations, for example, in the capacity of warehouses, transport units, and even budget. Now, the following question arises: What is the frequency and cost-efficient quantity in which each item must be replenished? This problem has been extensively studied and is known as the joint replenishment problem (JRP). Since its appearance in the works carried out by Miller & Starr, (1962), the JRP has been recognized for its potential for application in real settings. A considerable number of solutions and variations of the problem have been proposed during the last five decades. The greatest effort has revolved around finding the optimal solution. However, when the number of items is considerably large (50 or more), it is presumptuous to think of the optimum, considering that the problem is proven to be NP-Hard (Arkin, Joneja, & Roundy, 1989). Therefore, most authors have proposed heuristic procedures as a solution method. Aksoy & Erenguc (1988) reported a first bibliographic review of the solution methods available to that date. Later, Khouja & Goyal (2008) presented a new review of the research carried out between 1989 and 2005.

Some JRP assumptions generate controversy among academics and professionals, for example, not considering restrictions on storage capacity, neglecting lead times, assuming the compatibility of all items, and not allowing quantity discounts. In this research, a variation of the JRP is proposed, which considers restricted warehouse capacities, stochastic demand, and the possibility of joint replenishment of multiple non-competing buyers who employ multiple suppliers. This model was named by the author as the Stochastic Collaborative Joint Replenishment Problem (S-CJRP). Once the inventory model to be used has been defined, an additional difficulty arises. The generation of a collaborative agreement aims to generate surpluses or benefits that can be distributed among the participants; however, their contributions could be asymmetric. In this case, the allocation of benefits must be such that players receive equity in their returns, one perceived as *fair*, otherwise, the agreements may not be formed. To solve this situation, it is proposed the use of the techniques of Cooperative Game Theory (Neumann & Morgenstern, 1944).

Consequently, the ***general objective*** of this thesis is to evaluate to what extent collaboration in inventory replenishment enables reduction of the inventory cost by designing a procedure based on heuristics/meta-heuristics that successively integrates technics of optimization and Game Theory under stochastic demand, capacity constraints, multiple buyers, and for a fixed coalition of non-competing companies.

The ***specific research objectives*** are:

(1) To characterize the practical features of the inventory replenishment problem.

(2) To propose a heuristic/meta-heuristic procedure to solve an extension of the JRP called the S-CJRP, considering stochastic demand, multiple buyers, and logistical resource capacity constraints.

(3) To extend/modify the S-CJRP's solution procedure integrating an allocation technique to assign the expected value of benefits for each player belonging to a given coalition.

(4) To validate the proposed solution approach and determine the operating conditions that make feasible the operation of the collaborative strategy on which the S-CJRP is based.

In order to achieve such objectives, nine publications were made, and validated by peer reviewers and participants of 3 conferences (see section 1.3 for further description). Four theoretical and three practical contributions were made according with the framework proposed by Nicholson, LaPlaca, Al-Abdin, Breese, & Khan (2018) and specified in Section 1.3 as. Contributions are presented next, lowercase roman number are for practical contributions and uppercase for theoretical contributions:

For (1)

i. *The characterization of the typical process involved in the replenishment of inventory, a case study in Colombia.* The importance of this contribution is that recognizing in the practice these processes allows to determine the cost and time drivers of the replenishment of inventory more accurately, which are typically overlooked when designing inventory models.

ii. *The design of a cost structure to estimate the inventory management costs, including all those related to the inventory replenishment, enabling the estimation of the parameters of cost of the S-CJRP model and related extensions.* This validated structure help to fill the gap of the lack of knowledge about how to estimate inventory decision models parameters in the practice.

For (2)

I. *The introduction of a novel extension of the JRP named the S-CJRP, which deals with stochastic demand, non-zero lead times, multiple items and buyers, finite warehouse and transport capacities.* This set of features is commonly found in practical settings, but they have not been reported before. The model contributes to extend the scope of both current JRP theory and application.

For (3)

II. *The introduction of a novel eclectic heuristic approach that uses the S-CJRP model as means for identifying a collaborative agreement between different buyers jointly replenishing multiple items from multiple vendors, thus attaining economies of scale while reducing by sharing fixed procurement and operational costs.*

For (4)

III. *The improvement in the understanding of the S-CJRP model usefulness and indispensable policies for practitioners when implementing it.*

This contribution is composed by four contributions.

III(a). *The improvement in the understanding about how to exploit the S-CJRP potentials and the formulation of policies regarding coalition member selection to increase benefits and facilitates surplus allocation through the analysis of experimental settings for a variety of players with different features.*

III(b). *The improvement in the understanding of how the model can be a financially preferred alternative to access economies of scale from S-CJRP enabled cooperation than investment in individual capacity.*

III(c). *Insights and directions of why outsourced coordination seems to be the natural choice for S-CJRP coalitions, given the established high costs and risks of a discoordinated coalition operation that demands an expert coalition management.*

III(d). *Managerial insights about how to handle with the entry in a coalition of additional players, showing that generally requires not only additional expenditures but also a proposed prospect savings fee, which should be both charged to a newcomer as an entrance fee.*

Extra contributions: This contribution goes beyond of the original plan of the thesis; enabling an extra product consisting in a funded project described in Table 1-2 (Section 1-3) based on this contribution and the collaborative inventory model.

IV. *The introduction of the constrained stochastic multi-objective joint replenishment problem (S-MJRP), a novel JRP extension. The S-MJRP determines the efficient replenishment frequency and shipment size for multiple commodities with finite warehouse capacity, multiple transportation unit capacities and features, stochastic demand, non-zero lead-times and considering logistics costs and emissions as objectives.*

iii. *The improvement in understanding of the direct economic impacts of environmental policies on logistics practices, including inventory, replenishment, and fleet purchase decisions, when are imposed sustainability astringent policies. In this case, policies seeking to improve the environmental efficiency of transport activities by reducing overall transportation emissions, and by requiring a fleet mix that includes zero and near-zero emission vehicle technologies.*

The remaining of this document is organized as follows: **Chapter 1** describe the thesis background; motivation and the problem description, as well as, a description of the research products. A detailed explanation of the thesis contributions is presented in the following chapters. **Chapter 2** addresses contributions **(i)** and **(ii).** Later, **Chapter 3** deals with contributions **(iii), (iv)**, and **(v).** Next, **Chapter 4** focus on contributions **(vi), (vii)**, **(viii)**, and **(ix)**. Finally, **Chapter 5** addresses **(x)** and **(ix)**, and finals remarks are made in the last section.

CHAPTER 1. *Background, problem description, and research products*

The purpose of this chapter is to portray the thesis motivation and his context, to illustrate the problem and his background, to describe the research products, and to position contributions following a standard framework. In general, the chapter answers the following questions: What is the problem and its context? Why is it important? and what are the outcomes of the research and contributions?

1.1 Motivation

This section illustrates the motivations that led to the development of this thesis. In it, the current situation of the Colombian logistics performance is described in contrast to homologous nations in Latin America and nations belongings to the OECD. The results of this comparison give rise to the idea that alternatives are necessary to raise Colombia's logistics record, especially those processes that are related to international or cross-border logistics. Such motivations lead to the development of the logistics models described in the following chapters.

Reducing the logistics cost has been and still is today a big challenge for academics and decision-makers, an imposed requirement by the dynamic of the global business competition.

A logistical fortress such as reliability of the supply chain, flexibility, traceability, cost, and time efficiency could be an active part of the competitive advantage of companies. Even more in regions with comparative advantages as the northern coast of Colombia; a region well placed in logistical terms due to its closeness to large cargo corridors as the east coast of the U.S. and the Caribbean, but unfortunately with poor logistic performance when compared with first world countries.

In general, Latin American logistics indexes and especially cross-border services are not yet comparable with those of the rest of the OCDE member countries. The case of Colombia is not the exception, and it is one of the drivers for this work: to provide a timely, viable, and potentially effective solution to companies in the region to reduce their costs. This is why Section 1.1.1 addresses the case study of Colombia, introducing their logistic performance indexes and world rankings to glimpse the potential value of the proposal of this thesis.

The central motivation of this research is to improve understanding of the benefits in terms of costs and the logistical implications that would have to implement a collaborative strategy consistent on the joint replacement of inventories.

Collaboration in inventories, vertical and horizontal integrations are not new topics in the literature, as shown in Sections 1.1.2 and 1.1.3. However, the specific modeling of a collaborative strategy consisting on the coordinated replenishment of multiple companies under realistic settings and sharing their logistical resources is not oftentimes reported in the literature; even less, in connection to an effort to allocate the benefits obtained from the collaboration as part of such strategy. This collaborative strategy is especially interesting and desirable because it involves sharing risks (although not quantified in this research) and investments to jointly improve the efficiency of logistics activities. The possibility of leveraging investments thanks to better coordination and logistics operation is ultimately the main appeal of this strategy.

1.1.1 Overview of the Colombian logistics competitiveness

Measuring the productivity and efficiency of a supply chain is essential to identify their actual state of performance and to envision reengineering opportunities. In this sense, there are organizations such as APICS Supply Chain Council, who, through its SCOR® standard (Supply-Chain Council, 2008), strives to establish standards that allow estimating and comparing the performance of almost any supply chain. In addition, it establishes the best practices in the industry facilitating benchmarking. However, when it comes to measuring the logistical performance of a nation, the work turns out to be arduous and expensive, considering the time it takes to determine the logistics status of a supply chain and the difficulties that may be faced during its modeling (Georgise, Thoben, & Seifert, 2012; Huan, Sheoran, & Wang, 2004; Stewart, 1997).

The World Bank recognizes the importance of knowing the logistical status of nations, as an effort to collaborate in the economic growth of all regions of the world, and in this way fight poverty since the importance of logistics activity is recognized as a pillar for the growth of companies. The contribution of the World Bank consists of a series of reports that reveal the ease of doing business in each country of the world, and the effective practices implemented for this purpose. In one of his Doing Business reports; the Cross-border trade chapter, space is dedicated to determining the current performance of the facility to carry out international trade, measured in three aspect: time, cost and necessary documents (World Bank, 2020a, 2020b). There is a report dedicated exclusively to measuring logistics status: Logistics Performance Index –LPI- for its acronym in English(World Bank, 2007, 2018). This last indicator measures 6 dimensions related to merchandise exchange efficiency in 160 nations of the world. This report is based on surveys and measurements carried out by experts from each country. These dimensions are:

- **Customs:** efficiency of the clearance process (I.e., speed simplicity and predictability of formalities by border control agencies.
- **Infrastructure:** the quality of trade and transportation infrastructure.
- **Logistic competence:** the competitiveness and quality of logistics services; transporters, logistics operators and other intermediaries.
- **Tracking:** The ability to track and trace consignments.
- **Timeliness:** compliance with dates; the frequency with which a shipment meets the agreed delivery date.
- **International Shipments:** the ease of arranging competitively priced shipments

The Colombian case, is in particular contradictory, because despite its apparent geographical comparative advantage, its logistical performance is poor; the Caribbean coast of the country has a privileged geographical position, due to its proximity to the ports on the South and East Coast of the United States, which demand a high flow of cargo to and from the different South American countries. It would be expected that this advantage would have a high impact on the general economic development of the country, as a result of foreign trade activities, even more in the departments with port development such as Atlántico, Magdalena and Bolívar. However, the LPI shows that the country lags in performance when compared to its OECD member peers, Colombia is below the average for this group.

The positions occupied by Colombia in each version of the LPI have been: 82nd place in 2007, 72nd in 2010, 64 in 2012, 97 in 2014, 94 in 2016 and in the latest version (2018), reaching the position 58. Colombia had a notable advance from 2007 to 2012, later, the country in just two years, had an important detriment in the period 2012 to 2014 losing 30 positions. Recently the country had a significant improvement again climbing 36 positions. From the point of view of the integral performance indicator, which is the one used to position each nation, the values have been 2.50, 2.77, 2.87, 2.64, 261, 2.94 on a scale of 0 to 5, for 2007, 2010, 2012, 2014, 2016 and 2018 respectively (Germany has 4.2 points). Colombia has slightly improved since 2007 in its integral indicator; however, it must be considered that in general, most countries have improved their indicators due to the availability of our technologies and government efforts. It would be expected that Colombia would have a more notable development considering its geographical position and importance for the region. LPI measurements consider various aspects of the logistics chain that affect the competitiveness of companies such as Infrastructure, traceability, logistical suitability/competence, foreign trade, and customs.

The biggest challenges for Colombia are to improve the efficiency and predictability of customs processes (2.61 customs score), the reliability in time or the accuracy with which the agreed delivery dates are met (3.17 timeliness) and the infrastructure of ports and access routes, as well as the quality of the equipment used (2.67). In general, the country suffers from marked inefficiency in terms of time, while in terms of costs (measured by the component International Shipments) the country performs slightly below Chile and the OECD countries, meaning that still companies underperform in their competitivity when compared with most countries.

Figure 1-1. Shows a comparison of the results obtained by Colombia in contrast to the Germany (top result), Latin America and the Caribbean, Chile as the top country in the region, and the OCDE member countries. Compared to its Latin American peers, the country is slightly over average. Compared with the rest of the regions and countries, the lag in logistics is demonstrated. German outperforms almost 1.5 times the country's performance and almost twice to Latin America. One interpretation of these returns is that Latin American companies cost nearly twice as much to complete an import or an export, in addition to nearly twice the time, results that have a direct impact on their competitiveness. On the other hand, the report provided by the Doing Business (DB) (World Bank, 2020a), reveals that cumbersome customs procedures must be developed in Latin America and the Caribbean, ports are inefficient in operational terms and the countries' infrastructure is inadequate, in addition to astringent customs regulations, factors that generate high costs and delays in the import and export processes.

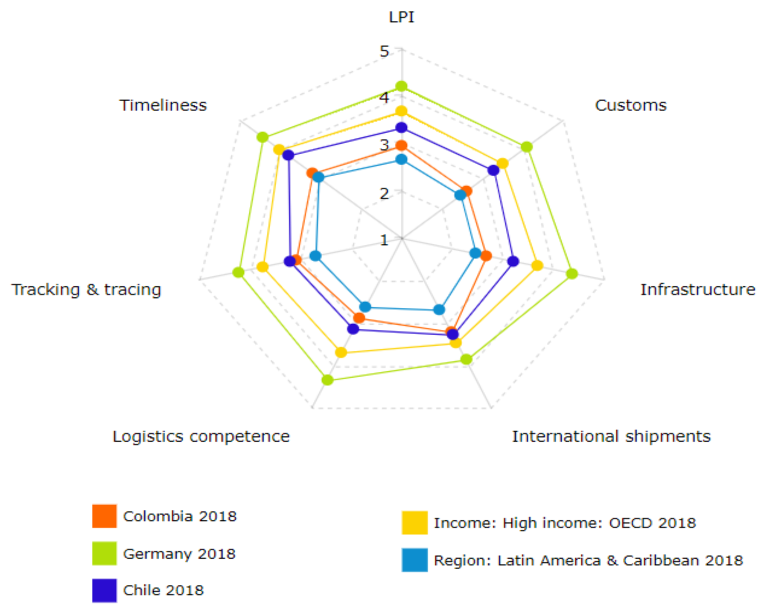


Figure 1-1 Radial graph for the LPI result for Colombia and other countries and regions, 2018. Adapted from: World Bank (2018)

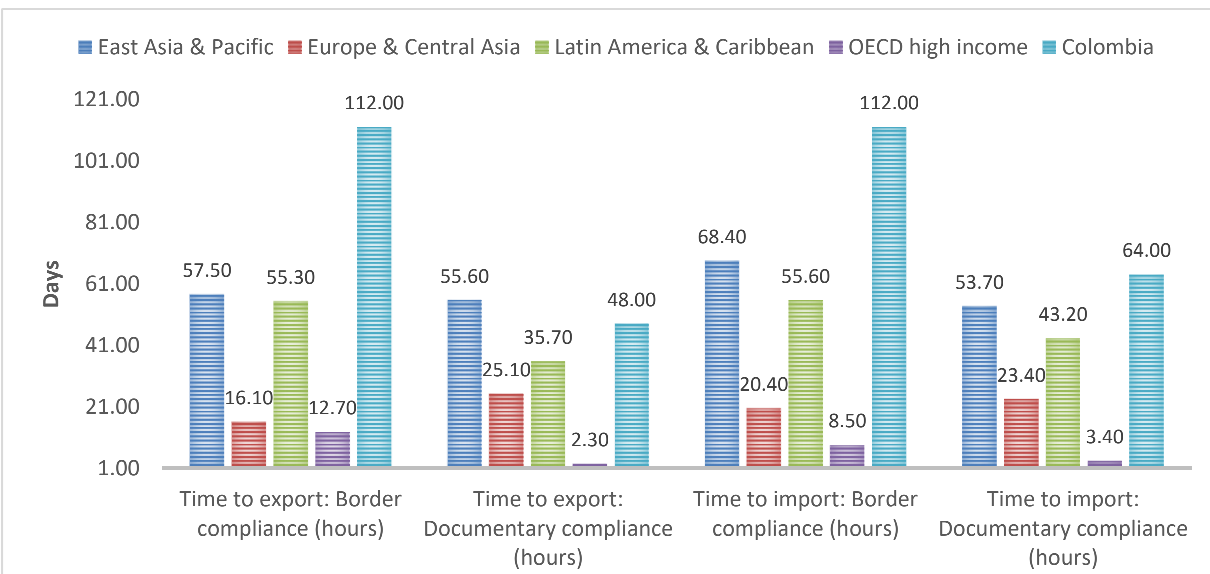


Figure 1-2: Time indicator result for cross-border trade section of the 2019 Doing Business report estimated for 40-ft containers and through seaports. Adapted from: World Bank (2020b)

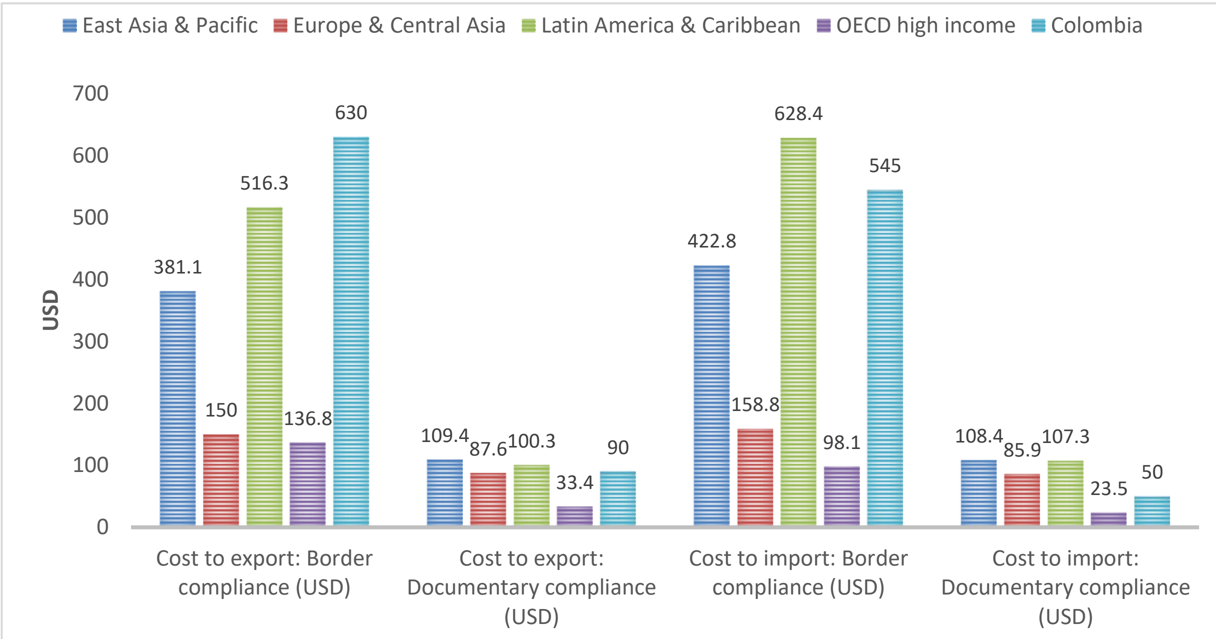


Figure 1-3: Cost indicators results for the cross-border trade section of the 2019 Doing Business report estimated for 40-ft containers and through seaports. Adapted from: World Bank (2020b)

Figure 1-2. shows that in the matter of time, Latin American countries take about 4.3 times more time to accomplish international compliances than OCDE high-income countries in export procedures through seaports. The Colombian case is even worse, with 8.8 times more than OCDE countries. Similarly, in the time related to complete legal documentation, Latin American countries take 15.5 times more time. For this specific component, the Colombian case is slightly better in the Latin American region (35,70 against 48 days). On the exports side, the case is similar; with a noticeable lag between Latin America and OCDE countries, Europe, and Asia. These excessive times represent money in withheld transit, and high opportunity costs, which undoubtedly affect the competitiveness of companies; a worrying situation considering that in the face of open trade agreements, Latin American companies would be at a disadvantage.

In terms of costs (Figure 1-3), it costs Latin American countries about 3.8 times more to complete an export using seaports in terms of border compliance; that is to say, to pay the expenses inherent to customs inspections and port operations. While for costs related to document compliance, Latin America maintains competitive costs with Europe and Asia, but not with OCDE member countries, which do so at a third of the cost. The outlook for imports is even less promising, considering that most of these countries depend on imports as a source of supply for consumer goods and trade. Covering customs and port fees for Latin American countries almost 6.5 times more than in OCDE countries, with Asia 3.7 times more and with European countries 4.3 times more.

In general terms, the competitiveness of the logistics in Latin American and in extension for Colombia is questioned since there are significate differences between the logistics indicators of these countries and OCDE members, Asia, and Europe. In this way, companies residing in countries with logistical development turn out to be more productive and competitive; many times, leaving those disadvantaged out of the game. Under this scenario, it makes sense to consider reengineering strategies that tend to improve the efficiency and productivity of the supply chain, as proposed in this research.

1.1.2 Potential of the collaborative strategies in the supply chain

The concept of collaboration in supply chain has evolved over time (Montoya-Torres & Ortiz-Vargas, 2014). One of the first definitions of collaboration in supply chain is given by Narus and Anderson (1996) who define collaboration as the cooperation between independent companies, somehow related, that share their own capacities and requirements with their clients. Similar terms, such as coordination, cooperation, strategic alliances, etc., have been employed in the literature (Bäckstrand, 2007; Montoya-Torres & Ortiz-Vargas, 2014). A wider definition can be obtained from the work of Simatupang and Sridharan (2005): Collaborate means to obtain common goals and objectives in order to create competitive advantage and higher (individual and global) incomes for the members of the supply chain than the ones that could be obtained if each member works on its own.

Traditionally it has been considered that collaboration can be developed *vertically* or *horizontally* (Barratt, 2007), however Chan & Prakash (2012) also include a *lateral* classification. The former consists of integration with suppliers (between logistics functions) and with clients, while the second refers to collaboration with competitors and with non-competing companies. It is important to note in this regard that in vertical collaboration companies share responsibilities, resources, and performance information to serve end customers. An example of vertical integration in the context of inventory management is provided by Alp, Ulk, & Nasuh C (2014) who present a joint replenishment model for multiple retailers, who make use of shared transportation units to reduce their costs. The strategy proves to have substantial cost benefits. Horizontal collaboration occurs between companies at the same level of the supply chain, while lateral collaboration is the combination of the benefits and capabilities of vertical and horizontal collaborations (Hsu & Hsu, 2008).

As a matter of fact, collaboration is oftentimes reported in the literature with good results in reducing logistics cost, enhancing service level, improving communications, reducing bullwhip effect, etc. (Ireland, R. & Bruce, 2000; Småros et al., 2003). In particular, strategies concerned with collaboration at the inventory management level have received special attention, considering the positive effect they pose over supply chain's effectiveness and profitability (Barratt, 2007; Fiestras-Janeiro, García-Jurado, Meca, & Mosquera, 2011; Holweg, Disney, Holmström, & Småros, 2005b). Some of the benefits reported by the literature and their sources through the use of these practices are presented below:

- Bullwhip reduction (Småros et al., 2003).
- Inventory level reduction, capacity use improvement, and supply chain flexibility (Disney & Towill, 2003; T. Zhang, Liang, Yu, & Yu, 2007).

- Reduction of supply times, increase in quality, faster innovation speed, quick resolution of problems, efficiency in technology transfer, increase in customer satisfaction and higher profitability (Fawcett, Magnan, & McCarter, 2008).
- Transportation resources efficiency improvement (Le Blanc, van Krieken, Fleuren, & Krikke, 2004).
- Reduction in transaction costs, increase in exchange of learning resources, knowledge exchange, reduction and control of supply risk, reduction of administrative costs, improvement of communication (F. T. S. Chan & Prakash, 2012).

1.1.3 Collaboration in inventory systems

The implementation of collaborative inventory strategies has been influenced by external drivers, such as the dynamics of competition, the rapid change in customer tastes, the speed of change in technologies, fluctuations in demand, the risk of technological obsolescence and financial pressures that demand a rapid return on investment and of course profitability (Fawcett et al., 2008). Collaboration offers the opportunity to develop differentiating and hardly-inimitable capacities that may well become competitive advantages (Simatupang & Sridharan, 2005).

An observed common benefit of collaboration in inventories is the reduction of the level of inventories, a highly desirable effect for companies, since it enables opportunities for reducing both management and operative costs. This makes sense considering that typically small and midsize companies have to replenish their inventories in relatively big lots to avoid large ordering costs, but punishing their holding costs and increasing their inventory risk (E.g., obsolescence, damage due to handling, or even robbery). In addition, Singer & Donoso (2007) add that this type of collaboration favors the cash flow, it induces a greater turnover of inventories and therefore capital. Further, when collaboration includes vertical integration, it facilitates the predictability of demand, leading to more accurate supplies: fewer inefficiencies, inventory collaboration could turn out in an improvement in the service level and supply reliability. Danese (2006) points out that the decrease in the number and frequency of run out inventories is a direct benefit of the supply chain integration; it improves the availability of inventories to customers, therefore increasing the level of service.

Seeking to exploit the mentioned benefits several collaborative inventory models have been analyzed by academics. E.g., Özen, Sošić, & Slikker (2012) exhibited an analysis of a decentralized inventory model made up of a manufacturer, a warehouse and a retailer. The authors demonstrated that by exchanging information, the demand forecast can be better calculated, improving the efficiency of the entire chain. Another representative example is the work carried out by Bartholdi & Kemahlioğlu-Ziya (2005), who tested the effectiveness of a centralized inventory or *pooling strategy* for manufacturer-retailer supply chains. In this work, the model was validated for two retailers, demonstrating the possibility of reducing inventory costs. The results are scalable for larger numbers of manufacturers and retailers. One of the challenges exposed for the *coalition* formation under of this type of strategy are the barriers placed by the players to share information. Under this issue, some authors have proposed solution strategies: contracts, capital commitment and joint investment, and negotiation strategies (Fiestras-Janeiro et al., 2011). Another outstanding example is the work by Yu (2010), who demonstrated that through supplier-distributor alliances, the cost of inventory of perishable products and the rate of non-fulfillment of orders can be reduced. Similarly, T. Zhang et al. (2007) showed that the inventory holding can be reduced by optimizing delivery transportation policies

On other lines, Chan & Prakash (2012) argue that lateral inventory integration policies are potentially more advantageous than horizontal and vertical ones. In a model where two manufacturers with continuous review provisioning policies (s, S) and (s, Q) integrate their inventory, the lack of information and the supremacy exercised by one of the two manufacturers in horizontal integration disadvantages the flexibility of the chain and inventory level, while when manufacturers knew each other's demand information, better forecasts were made that improved demand forecasts and reduced inventory levels. Other reference models are reported by Kelle, Miller, & Akbulut (2007); Zavanella & Zanoni (2009). In general, collaborative practices demonstrate great potential that can be exploited by those companies that are willing to share information. However, the testing of many other models and debate in the scientific community is necessary for their extension in the industry.

1.2 Problem description

Among the elements that make up the total cost of a product, the logistics cost is considered one of the most significant followed by the cost of the materials, especially when replenishment logistics operations involve cross-border movements (Chopra & Meindl, 2013). Among the typical activities of foreign trade, there are some especially expensive, such as transportation, nationalization or handling in ports and customs. Logistics costs are estimated to represent between 18% and 35% of the value of the final product in Latin America and the Caribbean, while in OCDE member countries (high income) they impact only 8% (Banco Interamericano de Desarrollo, 2014). The Latin American case is characterized by inefficient customs and port processes. It is regular for the loads that transit through these countries to face costs in foreign trade processes, especially due to the high number of documents required to complete either an import or an export, handling times in ports as a result of inefficient infrastructure, and due to the costs of non-competitive logistics operators (Banco Mundial, 2016).

From an economic perspective, a company facing high order costs is forced to increase the order quantity, which in turn generates additional but necessary costs for storage and inventory management. This is because the order size would normally exceed demand. For companies with a limited budget and logistical resources, the situation is even worse, as it may be desirable but not feasible to increase the order quantity to achieve scale changes. Therefore, it is deductible that there are many professionals in various business environments with this concern, so the question of how to increase or maintain cargo size in economical quantities while maintaining inventory costs under control remains relevant. In this sense, the development of inventory models with collaborative approaches has reported promising results in terms of reducing costs, increasing the level of service, improving chain resistance and the potential creation of competitive advantages (G. P. Cachon & Netessine, 2006; F. T. S. Chan & Prakash, 2012; Chen & Chen, 2005). Collaboration in inventories is especially attractive because it allows the use of shared logistics resources, such as warehouses, transport units, personnel, or even technologies at the service of inventory (Arango Serna, Adarme Jaimes, & Zapata Cortés, 2013).

From the Game Theory perspective, sharing inventory costs has been addressed in a field known as Inventory Games (Meca, Timmer, García-Jurado, & Borm, 2004). Within this literature, the high potential of collaborative strategies to reduce logistics costs is once again recognized. However, it should be noted that the topics related to the Inventory Games revolve around guaranteeing stability between cooperation agreements, but not the design of inventory systems that reflect real-life situations, mostly the classic EOQ model is addressed (Dror & Hartman, 2011).

On the other hand, determining the frequency and quantity with which an inventory must be replenished is one of the frequent problems in the literature, especially when replenishment involves the coordination of multiple items. Multi-item replenishment is economically more desirable than individual replenishment since the unit logistics cost could be decreased by exploiting economies of scale. This problem is known as the Joint Resupply Problem (JRP). For decades there has been great interest in solving the JRP efficiently (Khouja & Goyal, 2008), considering that this is an NP-Hard problem (Arkin, Joneja, & Roundy, 1989). Most of the proposed solution methods have been heuristic and meta-heuristic. A more extensive discussion of the JRP is presented in Chapter 3.

This research deals with proposing and solving an inventory model that reduces the logistics cost of a fixed group of players (companies) who, through a cooperation agreement, coordinate the replenishment of their inventories while sharing transport units and warehouse storage, when they face a stochastic demand that follows a normal distribution.

The hypothesis of this research is that the association between companies that do not necessarily belong to the same supply chains could reduce the cost of individual replenishment, by implementing the logistics strategy implied by the S-CJRP.

The first challenge is to design a solution strategy that delivers results in a moderate computational time. In a practical way, solving this model would solve the following questions: How often should the replenishment of each item of the players be carried out? And what should be the order size of each item?

On the other hand, the coordination of the replenishment of multiple items allows taking better advantage of the fixed costs of the process, generating a series of savings that can be defined as the difference that exists between the regular cost of acting individually, and the cost that a player could cope by acting collaboratively. However, to access such savings, players in an agreement (coalition) must incur a number of coordination costs, or the costs necessary to implement the collaborative agreement. The allocation of such costs is fundamental for the stability of the coalition, since acting rationally, a player would accept only those agreements where his savings and those of the other players are a reflection of his investments and contributions, otherwise, the coalition would not be formed. In other words, and from the perspective of cooperative game theory (Neumann & Morgenstern, 1944), players would be willing to accept only "fair" allocations. Additionally, under the approach of this research, players would accept allocations not only considering the concept of justice but also that of economic convenience. In such a case, despite receiving fairness in the assignment, the players would reject an agreement if they find that their return is not attractive. Further discussion of this situation will be presented in Chapter 3, Section 3.4.3. Considering the aforementioned, the following question arises: How should the benefits obtained be assigned to the players?

Finally, it is to be expected to find asymmetry in the characteristics of the players and their cargo profile, this is, Coalitions formed by players with high demands and high costs could affect the total benefit obtained from players with low demands and low cost. Another example of this situation is the agreement between players with large differences in their lead times, players with a short lead time could increase their cost of maintaining by forming agreements with players with long lead times. Considering the above, it is important to determine how the difference in the company's profiles affects the potentials savings, and how to anticipate situations to avoid non attractive savings.

After evaluating the above questioning and problems, the following research question arises: *How does collaborating on inventory replenishment reduce the cost of replenishment when facing stochastic demand, multiple buyers and sellers, and capacity constraints for a limited coalition?*

1.3 Description of the research contributions and products

This section aims to expose and clarify the products obtained during the research work, as well as, to claim the contributions in justice of its scientific value. We will first cover the contributions, to then proceed with the research products.

1.3.1 Contribution positioning

This section aims to elicit the scientific/theoretical contributions declared by the author through the use of an established conceptual framework by Nicholson et al. (2018). Such framework provides guidance to doctoral examination committees, journal editors, and paper peer reviewers to examine and classify the contributions claimed in a work, and we have found it of use to position the contributions introduced with this research.

Table 1-1 lists the thesis contributions and sort them by importance and chronological order. it classifies them as well by category following the aforementioned framework. The importance order refers to the author's consideration regarding the magnitude of the value for science.

Table 1-1. Thesis contributions list

Importance order	Contribution category	Contribution
I*	Differentiated context and Revelatory	The introduction of a novel extension of the JRP named the S-CJRP, which deals with stochastic demand, non-zero lead times, multiple items and buyers, finite warehouse and transport capacities. This set of features is commonly found in practical settings, but they have not been reported before. The model contributes to extend the scope of both current JRP theory and application.
II	Differentiated context	The introduction of a novel eclectic heuristic approach that uses the S-CJRP model as means for identifying a collaborative agreement between different buyers jointly replenishing multiple items from multiple vendors, thus attaining economies of scale while reducing by sharing fixed procurement and operational costs.

III		Differentiated context and Replicatory	The improvement in the understanding of the S-CJRP model usefulness and indispensable policies for practitioners when implementing it.
	III(a)	Differentiated context and Replicatory	The improvement in the understanding about how to exploit the S-CJRP potentials and the formulation of policies regarding coalition member selection to increase benefits and facilitates surplus allocation through the analysis of experimental settings for a variety of players with different features.
	III(b)	Differentiated context and Replicatory	The improvement in the understanding of how the model can be a financially preferred alternative to access economies of scale from S-CJRP enabled cooperation than investment in individual capacity.
	III(c)	Differentiated context and Replicatory	Insights and directions on why outsourced coordination seems to be the natural choice for S-CJRP coalitions, given the established high costs and risks of a discoordinated coalition operation that demands an expert coalition management.
	III(d)	Differentiated context and Replicatory	Managerial insights about how to handle with the entry in a coalition of additional players, showing that generally requires not only additional expenditures but also a proposed prospect savings fee, which should be both charged to a newcomer as an entrance fee.
IV		Incremental	The introduction of the constrained stochastic multi-objective joint replenishment problem (S-MJRP), a novel JRP extension. The S-MJRP determines the efficient replenishment frequency and shipment size for multiple commodities with finite warehouse capacity, multiple transportation unit capacities and features, stochastic demand, non-zero lead-times and considering logistics costs and emissions as objectives.
i		Practical	The improvement in understanding of the direct economic impacts of environmental policies on logistics practices, including inventory, replenishment, and fleet purchase decisions, when are imposed sustainability astringent policies. In this case, policies seeking to improve the environmental efficiency of transport activities by reducing overall transportation emissions, and by requiring a fleet mix that includes zero and near-zero emission vehicle technologies.
ii		Practical	The design of a cost structure to estimate the inventory management costs, including all those related to the inventory replenishment, enabling the estimation of the parameters of cost of the S-CJRP model and related extensions.
iii		Practical	The characterization of the typical process involved in the replenishment of inventory, a case study in Colombia. The importance of this contribution is that recognizing in the practice these processes allows to determine the cost and time drivers of the replenishment of inventory more accurately, which are typically overlooked when designing inventory models.

Uppercase for theoretical contributions, lowercase roman number are for practical contributions.

The framework first establishes that a scientific contribution must include an assessment of five dimensions: ***(I) Interestingness, (II) Utility, (III) Originality and Value, and (IV) Progress.*** Interestingness in this context means “advancing knowledge in a way that is deemed to have utility or usefulness for some purpose”. A contribution builds or extends theory, it provides progress in the discussion, “it is something that embellishes or creates something beyond what is already known” and “it is interesting because provides utility, usefulness or value to at least one audience whose knowledge is advanced by considering an argument or the findings of a study" (Nicholson et al., 2018). The authors also propose that each contribution has a magnitude, but they are not all equally utilitarian, useful, or valuable. Moreover, the magnitude of a contribution can only be post-rationalized. Regardless of submission with the former aspects, the scientific method must be fully complied.

Under this method, only conceptual and empirical contributions are considered. It disregards practical contributions, as they lack progress due to the fact they are based on existing theory. Conceptual contributions improved conceptual definitions of previous constructs or identify conceptual definitions of additional constructs to be added to the conceptual framework. Additional theoretical linkages with their accompanying rationale are also included in this category, including the development of improved theoretical rationale for existing linkages. On the other hand, empirical contributions test established constructs and generate knowledge from such tests. It includes testing theoretical linkages between two constructs that have not previously been tested or examining the effects of a potential moderator variable on the nature of the relationship between two constructs. Practical contributions do not add value to the theory since lack of the scientific method (at least partially) and/ or are based on known theory. The semantics of this method are presented in Figure 1.4, to then move on to the specifics of each of the contributions previously listed. The strategies for claiming a theoretical contribution can be articulated into five main meta-strategies: incremental, revelatory, replicatory, differentiated context, and consolidatory, with nine specific sub-strategies.

The kind of contributions claimed using the ***incremental*** strategies are based on the traditional gap spotting approach to reviewing literature. In Nicholson et al. (2018) metaphorically it is suggested that it consists of filling the missing brick in a wall that the researcher diligently provides. However, a gap might exist because there is no value in filling it. In detail, this strategy approaches the gap spotting strategy through two sub-strategies: ***confusion spotting*** and ***neglect spotting***. Confusion exists when a collection of articles published within a topic fails to reach a consensus on a topic. The second specific strategy, neglect, focuses on overlooked or under-researched areas, "in which neglect could apply to theories, constructs or methodologies, but could also refer to areas where papers are substantially conceptual rather than empirical".

Revelatory contributions (revolutionary science) juxtapose incremental contributions (normal science) and arises when theory reveals what we otherwise had not seen, known, or conceived. This category is composed by two strategies. The first, ***assumption challenging or problematization***, which consists on articulating existing assumptions and challenges them. The second, the ***multiple lenses*** strategy, refers to the process of importing a theory from one discipline into another (theory borrowing) and then combine concepts and constructs from two or more disciplinary areas (theory blending).

The ***consolidatory*** contributions are mainly dedicated to research reviews that promote the consolidation of scientific advance knowledge under some method. Papers referred to as state-of-the-art belong to this category. Within these contributions there are three subcategories. The first is the ***systematic review***, where the focus is to obtain general and indeed replicated results to some extent based on a standard and known method. It can be qualitative, quantitative or both. The second is the ***traditional review***, which is a narrative revision involving a conceptualization of the available literature in a subjective manner. The third is the ***meta-analysis***, in which hypotheses are tested by aggregating the empirical findings from different studies, as well as inspecting the sampling instruments used in each case. In this category the existence of statistical analyses is central.

Replicatory contributions are characterized by duplicating previously published empirical studies in order to confirm whether similar findings can be obtained under the same settings, or whether the results persist under different settings. Two strategies belong to this meta category. All of them have three common design aspects: conceptual, methodological, and substantive. First, ***exact replication***, which refers to a statistical replication involving drawing the same correlations between the same variables in the same way, using the same procedures with a different sample from the same population. The second, ***close replication,*** slightly varies the three aspects of design.

Finally, the meta category ***differentiated context*** contributions are the interception between incremental contributions and replicatory contributions. To this category belongs differentiated replication strategies, where variances in the three aspects of design of the replicatory studies are deliberately designed to establish the generalization of a previous study. In addition, it intends to fill a gap offered by identifying a new application or context for an existing theory. A common approach is to identify an explored "thing" that through extension and application to an unexplored "thing" will further understanding in some way.

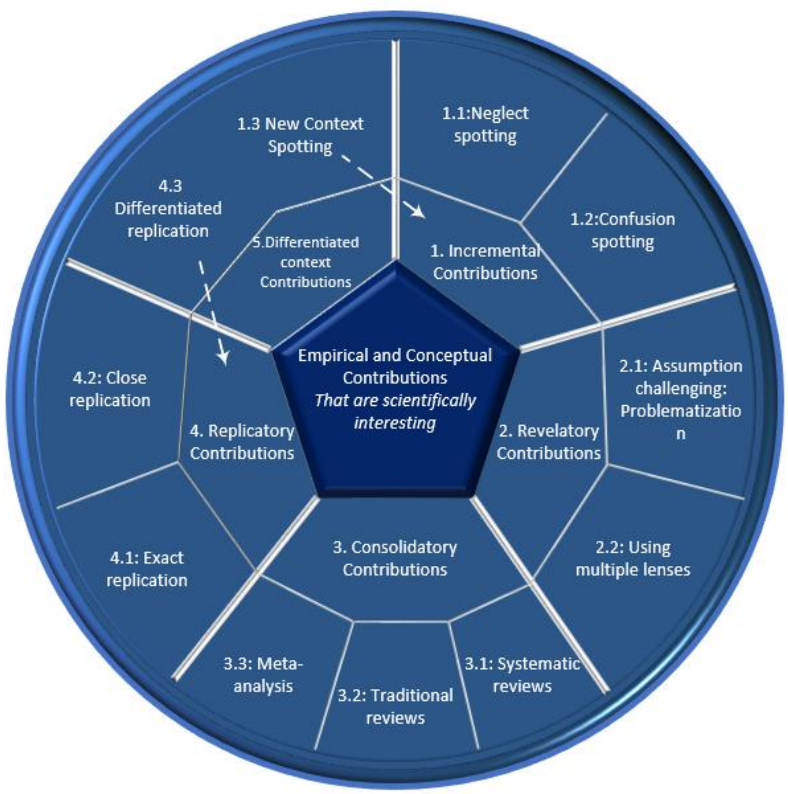


Figure 1-4: Contribution conceptual framework. Adapted from Nicholson et al. (2018)

Next are positioned the thesis contributions according to the commented framework in order of importance, according to Table 1-1.

I. *The introduction of a novel extension of the JRP named the S-CJRP, which deals with stochastic demand, non-zero lead times, multiple items and buyers, finite warehouse and transport capacities.* This set of features is commonly found in practical settings, but they have not been reported before. The model contributes to extend the scope of both current JRP theory and application.

Interestingness, utility, originality and value, and progress: The S-CJRP model is useful and interesting for both practitioners and academics in the area of logistics. Nevertheless, it is particularly useful for practitioners who can take advantage of a model that addresses a well-known problem: high replenishment costs and inefficiency in the use of logistics resources. The model combines various elements observed in practice and brings them together in a mathematical model, which is a better representation of reality when compared with classical JRP model extensions.

Unlike the classic JRP model, and some recent extensions (arranged in a comparison available in Table 3-1), the S-CJRP model also considers warehouse and transport unit capacities and other elements observed in reality. Furthermore, the model considers multiple buyers, unlike the JRP model and many of its extensions that consider a single buyer. With the aim to incorporate more real-life elements, demand is considered stochastic, and non-zero lead times are incorporated. In contrast, most models consider demand deterministic and do not consider non-zero lead times. The model is also incorporated with the Shapley function by means of a heuristic that facilitates the allocation of the savings exploited by the model.

In general, the model is original and valuable, because such a combination of assumptions is novel (at least until the date of its publication) and extends its use to include widespread practical settings previously neglected. The model offers progress in theory, especially in the field of inventory theory that for almost 60 years has revolved around finding models and strategies that can be optimally solved, leaving aside the real needs of the industry (Khouja & Goyal, 2008).

Contribution category: The strategy used to claim a theoretical contribution, in this case, is the gap spotting in the meta category differentiated context according to the revised conceptual framework by Nicholson et al. (2018). The proposed model takes elements of the classical JRP theory and extends it to a novel context, a collaborative inventory model. In general, the contribution extends extant research, as shown in Section 3.3 literature review where the gap that fills the model is established. In addition, the assumption challenging strategy is used, given that the assumptions of the model were re-thought to create a more realistic model. In consequence, this contribution is both Revealing and Differentiated Context contribution.

II. *The introduction of a novel eclectic heuristic approach that uses the S-CJRP model as means for identifying a collaborative agreement between different buyers jointly replenishing multiple items from multiple vendors, thus attaining economies of scale while reducing by sharing fixed procurement and operational costs.*

Interestingness, utility, originality and value, and progress: This eclectic heuristic claimed as a theoretical contribution is interesting and useful for both academics and practitioners, since it offers the means for identifying the potential individual savings by implementing the collaborative strategy implicit in the S-CJRP.

Thanks to the use of this heuristic, players can determine their interest in forming a given coalition on the criteria of fairness and economic convenience. The first concept is inherited from the use of the Shapley function, which has the advantage of allocating individual benefits according to the marginal impact of each player to reduce the total costs of the entire coalition. The second concept assumes that the players would accept to be part of a coalition if it is economically convenient according to their expectations and their opportunity cost. Both concepts must be satisfied, since even a coalition that is economically convenient may not be stable if it is perceived as unfair.

Although there is a previous report of the use of the Shapley function to assign inventory costs between players, this heuristic features as well the particularity of being assembled and seamlessly fitted into the S-CJRP model mechanics, which makes it computationally efficient. The three-step heuristic (described in Chapter 3) has the advantage of creating the characteristic functions (the function that determines the expected cost of forming a coalition) of each coalition based on a generic function that works for any set of parameters. It does not require extra processing during its execution or post-processing. Unlike many applications observed in the literature, it is common to observe that each coalition has a particular characteristic function, complicating the processing. This characteristic function is efficiently resolved by means of a genetic algorithm, which in spite of not guaranteeing optimality, it reaches good quality solutions (empirically verifiable when compared with the individual or non-collaborative method) with exponential execution times (the Shapley function must be executed $2^{|N|} - 1$ times). In practice, this computational limitation does not represent a problem for small coalitions (up to 5 members). Coalitions are naturally expected to be small due to the difficulty of coordination between companies.

The proposed formulation does not guarantee core stability (there is no more convenient coalition than the proposed coalition). Furthermore, the game is not super-additive in all cases (further discussion is provided in Section 3.4.3), that is, the grand coalition implies the best allocation. However, from the analysis of scenarios it was observed that more than 90% of the coalitions were super-additive. Nevertheless, this heuristic fully rests on the concepts of justice and economic convenience described above.

The originality, value, and progress in the science of this heuristic is that, it brings an alternative use to classical game theory. It offers a practical mechanism that provides a sense of confidence to the public. Certainly, its main value is attached to the new context where it is proposed. Historically, modelers in this area have devoted great effort to satisfy the fundamental structures and properties (such as the super-additivity), thus limiting the scope of models to represent the real business dynamics and their claims, that, as previously indicated, not only bases its decisions on criteria such as core stability.**Contribution category:** This is classified as a Differentiated Context contribution because it is based on a new application or context of an existing theory. It implies an alternative approach, in this case, the use of the Shapley function and the JRP model as strategy to conform coalitions. This scarcely explored use allows a new debate in the theory of cooperative games. Shapley's function is mainly used because of its property of fairness without strictly considering the satisfaction of stability in the sense of the core. However, it still demonstrates benefits and usefulness when compared to the regular allocation strategy or linear allocation by cargo volume.

The next contributions claim overall and specific theoretical contributions. They are posed as a whole, synthesized in single one.

III. *The improvement in the understanding of the S-CJRP model usefulness and indispensable policies for practitioners when implementing it*.

III(a). *The improvement in the understanding about how to exploit the S-CJRP potentials and the formulation of policies regarding coalition member selection to increase benefits and facilitates surplus allocation through the analysis of experimental settings for a variety of players with different features.*

III(b). *The improvement in the understanding of how the model can be a financially preferred alternative to access economies of scale from S-CJRP enabled cooperation than investment in individual capacity.*

III(c). *Insights and directions of why outsourced coordination seems to be the natural choice for S-CJRP coalitions, given the established high costs and risks of a discoordinated coalition operation that demands an expert coalition management.*

III(d). *Managerial insights about how to handle with the entry in a coalition of additional players, showing that generally requires not only additional expenditures but also a proposed prospect savings fee, which should be both charged to a newcomer as an entrance fee.*

Interestingness, utility, originality and value, and progress: This group of empirical contributions are interesting and especially useful for practitioners. Considering that the S-CJRP model is theoretical and new, with no reports of its use in practice, these contributions seek to improve the understanding of its operation and advantages of the collaborative strategy proposed by the model from different perspectives.

First, through exhaustive simulation of multiple scenarios, it is shown that the model allows for significant savings, around 28.4% compared to the individual or regular method, even when stochastic lead times are considered. The stochasticity of lead time implies eventual delays in the shipment of items, generating shipping over costs. Second, by improving understanding about the S-CJRP's mechanisms generating economies of scale and subsequently savings, players could find in the collaborative method an alternative for expanding logistics resource capacity. Third, case analysis suggests that sub-contracting for replenishment coordination is a more convenient alternative than insource coordination. Finally, given the potential scenario in which new players wish to be part of a previously established coalition, directions are offered on to how to manage the possible entry of these players in a convenient way for the coalition.

The originality of these contributions lies in the fact that such knowledge has not been previously reported, given that the model is relatively new and hence there are few cases in the literature where the potential operation of JRP extensions is discussed. These contributions offer progress in theory as they reveal the potentials of the S-CJRP model.

Contribution category: The classifications in this case are both replicatory and revelatory contribution. The first because a replication was made with moderate changes: changes in the method of solution and analysis, in addition to the implementation of a policy (on the shipping cost for delayed orders) that affects the total cost of replenishment. The subcategory in this case is differentiated replication. The second corresponds to a reconsideration of the assumptions: lead times considered deterministic in the model S-CJRP now are considered stochastic, the number of players could change, as well as the capabilities of logistics resources.

IV. *The introduction of the constrained stochastic multi-objective joint replenishment problem (S-MJRP), a novel JRP extension. The S-MJRP determines the efficient replenishment frequency and shipment size for multiple commodities with finite warehouse capacity, multiple transportation unit capacities and features, stochastic demand, non-zero lead-times and considering logistics costs and emissions as objectives.*

Interestingness, utility, originality and value, and progress: Similar to the S-CJRP model, the S-MJRP model is useful and interesting for both practitioners and academics. However, in this case, it is not only of interest to practitioners in logistics but decision-makers who aim to create policies/strategies to mitigate climate change through the use of cleaner vehicles. The S-MJRP reveals the trade-off between inventory costs and transportation emissions involved in a single supplier-retailer replenishment process (a relationship barely explored), while considering budgetary constraints and CO_2 emission reductions. The utility is twofold. For decision-makers in companies, the model helps to determine both inventory policies and fleet composition in a cost-efficient manner when there are goals (voluntary or regulated) of emission reductions, or mandates for cleaner fleet compositions, among other types of sustainable policies. For transportation planners, it allows determining the financial need of companies when faced with regulatory policies.

Similar to the S-CJRP, the S-MJRP collects various elements observed in practice and brings them together in a mathematical model. However, the particular novelty from the S-MJRP approach is that it considers an additional objective beyond the inventory cost reduction. In the JRP-related literature, most of the models and approaches concentrate on finding the optimal replenishment strategy that minimizes monetary costs. The S-MJRP model considers limited budget and warehouse capacities, a variety of transport unit technical features, including diesel, hybrid, and zero-emissions vehicles. Typically, JRP extensions neglect to model transportation features or only consider a single kind of vehicle. Also, the model considers stochastic demand and non-zero lead times. Such features make the S-MJRP original and able to claim progress in theory, in particular, multi-objective models are scarce in the JRP literature but recently academics have shown interest in them since they have a significate potential to be applied in real settings.

Contribution category: This contribution is incremental in the neglect sub-category. The gap spotting strategy is used, introducing a new valuable model extension significantly different form the original S-CJRP. The literature had not considered modern limitations such as restrictions on the level of emissions or on the fleet configuration as strategies to reduce emissions. In addition, the proposed model considers the relationships that exist between fleet and inventory decisions, a very little explored combination.

Considering the previous concepts, tree contributions were classified as *practical contributions*, and thus excluded of this *theoretical* analysis. However, it should be noted that practical contributions, despite their nature, effectively add value and are of interest in some fields.

i. *The design of a cost structure to estimate the inventory management costs, including all those related to the inventory replenishment, enabling the cost parameters estimation of the S-CJRP model and related extensions.*

It was not possible to determine if this structure can be considered an unbiased estimator of the cost parameters of the JRP or S-CJRP model, the validation process was insufficient. Although the cost structure is conceptually correct, the contribution is still considered as practical. Although, these types of structures are typically validated to the extent that they are applied. Still, after reviewing the literature, it can be stated that this structure helps to fill the gap of the lack of knowledge about how to estimate inventory decision model parameters in practice. Typically, literature indicates cost drivers, but it does not indicate how to actually calculate them. Despite its limitations, the tool is original and offers progress in the scientific discussion.

ii. *The characterization of the typical process involved in the replenishment of inventory: A case study in Colombia.*

This contribution could be interesting for some practitioners in the field of logistics, however, it does not advance the knowledge; rather, is a formal representation of the know-how (although typically no documented). The inventory replenishment process is well known for practitioners specialized in foreign trade, so the representation of them does not add enough value to claim an original contribution. This contribution is more concerned with the actual use and has value for training purposes for new practitioners in the field. The value of this contribution is that describing how these processes are developed in practice allows us to determine the cost and time drivers of the replenishment of inventory more accurately. These aspects are typically overlooked when designing inventory models that intend to be used in real settings. Although depending on the industry these processes could be different, this work is comprehensive in displaying such elements and linking them in a logical framework.

iii. *the improvement in understanding of the direct economic impacts of environmental policies on logistics practices, including inventory, replenishment, and fleet purchase decisions, when are imposed sustainability astringent policies. In this case, policies seeking to improve the environmental efficiency of transport activities by reducing overall transportation emissions, and by requiring a fleet mix that includes zero and near-zero emission vehicle technologies.*

This contribution is classified as a practical contribution for two reasons. First, it is strictly concerned with experience or actual use and/or potential results by using the model previously proposed (exposed in contribution (IV)), which has already claimed and demonstrated originality, utility, interest, and progress. Second, the strategy used to claim contribution, lacks the scientific method structure, specifically lacks hypostatization for proving new theories.

1.3.2 Research products

This thesis lasted 5 years, within which 11 direct products and 4 indirect products were generated. The direct products range from peer-reviewed scientific journal papers to funded-projects and presentations in international conferences, highlighting that to the date of this writing has rendered two full-paper publications in both Q1 and Q2 indexed journals and numerous in-press and forthcoming works. The indirect products correspond to 3 bachelor capstone projects and 1 master's thesis on progress. The thesis contributions and their relationship with the objectives are described in Figure 1-5. The detailed list of products is available in Table 1-1. Next, a brief overview of such products is provided:

1. **Quick methodology based in the SCOR model for supply chains reengineering of international trade:** This presentation/extended abstract reported the development of a methodology designed by the author to reduce the time to characterizing a Supply Chain using the SCOR ® standard. The author also discusses strategies about how to extend the SCOR ® standard to services and retailers companies. This methodology was used for the outputs of Chapter 2.

2. **A cost- effective collaborative inventory management strategy between non-competitor companies - A case study:** This paper and its presentation reported a real case study for Colombian companies using the collaborative inventory model, the purpose was to demonstrate that inventory collaboration has the potential to reduce logistics costs. A preliminary but different heuristic was used to solve the model than from the one reported later in the S-CJRP model. The paper and presentation won the *Best Paper Award*.

3. **Intervención sobre prácticas integrativas en el clúster de logistica del Atlántico; Cáp 1: Desarrollos metodologicos:** This chapter covers a methodological design that integrates world bank methodologies in its Doing Business, LPI, SCOR ® indicators and the author's proposals to design a new methodology that allows typifying (in procesess, times, and costs) foreign trade supply chains in time and reduced cost with greater precision and reliability. Part of the methodology was used for the development of Chapter 2.

4. **Intervención sobre prácticas integrativas en el clúster de logistica del Atlántico; Cáp 2: Muestra de cadenas de suministro diagnosticadas:** This chapter is a sample of the results of the application and interpretation of the developments in Chapter 1 of the book. Similarly, this developments are useful for the Chapter 2 (from the current document).

5. **Maximization of profits in import activities through a hybrid algorithm based on fictional games with multiple suppliers.** This article reports an alternative based on a collaborative inventory strategy; fictitious games. The results showed the potentials in reducing re-stocking costs thanks to the collaborative practices of joint inventory management.

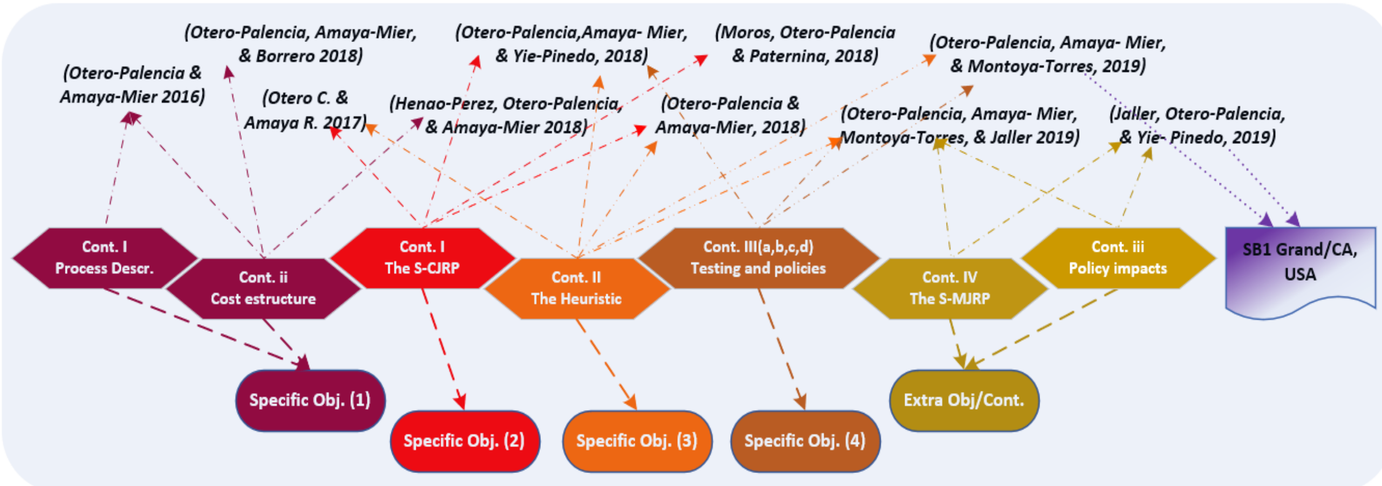


Figure1- 4 Thesis contributions in link with the research outputs, and the objectives.

6. **A collaborative logistic cost-reduction strategy (S-CJRP) for non-competitive small and medium sized enterprises:** In this conference were presented the S-CJRP model and its solution method to validate their scientific value. The contributions receive positive feedback. Later, the work was invited to be extended and submitted to Transportation Research Part A.

7. **A stochastic joint replenishment problem considering transportation and warehouse constraints with gainsharing by Shapley Value allocation:** This is the central work of this thesis. It officialy reports the S-CJRP model and their solution procedure, as well as part of the validation.

8. **A Collaborative Logistical Cost-Reduction Approach for Non-Competitive Small-And Medium-Sized Enterprises: Exploring S-CJRP Coordination and Variability Aspects Through Discrete-Events Simulation:** This work is an extension of the previous work, it covers a large part of the model validation, and also through the use of discrete simulation and the analysis of scenarios allows to determine the robustness of the collaborative strategy, it also allows to glimpse new possible situations to consider during their operation.

9. **Inventory and fleet purchase decisions under a sustainable regulatory environment:** This work introduce a JRP novel extension; the S-MJRP determines the optimal replenishment frequency and shipment size for multiple commodities with warehouse and transportation (number of vehicles) capacities considering logistics costs and emissions as objectives.

10. **Development of a Logistics Decision Support Tool for Small and Medium Companies to Evaluate the Impacts of Environmental Regulations in California.** This project has three central objectives: to develop strategies to leverage the purchase of cleaner vehicles based on a more efficient inventory replenishment (Model M-SJRP). Second, it seeks to design an interactive tool that allows users to determine what their inventory replenishment policy and their fleet composition should be to efficiently reduce their costs and CO2 emissions. Third, it seeks to explore the benefits of collaborative inventory practices in California supply chains. The work is based in all the contributions of this thesis.

11. **Supply Chain Management and Logistics in Latin America: A Multi-Country Perspective; Chapter 39: Collaborative Inventory Replenishment: Discussions and Insights of a Cost-effective Alternative for Non-competitive Small and Medium-sized Enterprises:** This work is integrative in its nature and summarizes all the contributions, as discussed in the coming section. it offer further discussions about collaboration in inventory; opportunities and challenges for small and medium companies in Latin America, as well as, directions for future opportunities and extensions of the JRP model.

Three bachelor final projects related to this research were completed in the Universidad del Norte (Table 1-3), which were co-supervised by the author. Additionally, a master's thesis is underway, which addresses a multi-objective extension of the S-CJRP model incorporating quantity discounts, trade credits, and cash flow metrics.

Table 1-2: Research products

#	Year	Type of product	Name	Status
1	2016	International conference presentation, IEOM Society, Kuala Lumpur, Malaysia. 2016	Quick methodology based in the SCOR model for supply chains reengineering of international trade. International Conference on Industrial Engineering and Operations Management, Kuala Lumpur, Malaysia. (Otero-Palencia & Amaya-Mier 2016)	Available on: http://ieomsociety.org/ieom_2016/pdfs/556.pdf
2	2017	SCOPUS proceding and presentation * ***Best track paper award winner,*** IEOM Society, Bogotá, Colombia 2017	A cost- effective collaborative inventory management strategy between non-competitor companies - A case study. (Otero C. & Amaya R. 2017)	Available on: http://ieomsociety.org/bogota2017/proceedings/
3	2018	Book Chapter, Ediciones Uninorte, 2018	Intervención sobre prácticas integrativas en el cluster de logistica del Atlántico; Cáp 1: Desarrollos metodologicos. (Otero-Palencia, Amaya-Mier & Borrero 2018)	Published: Ediciones Uninorte, ISBN 9789587419689
4	2018	Book Chapter, Ediciones Uninorte, 2018	Intervención sobre prácticas integrativas en el cluster de logistica del Atlántico; Cáp 2: Muestra de cadenas de suministro diagnsticadas. (Henao-Pérez, Otero Palencia & Amaya-Mier, 2018)	Published: Ediciones Uninorte, ISBN 9789587419689
5	2018	International SCOPUS conference proceding, IEOM Paris, 2018	Maximization of profits in import activities through a hybrid algorithm based on fictional games with multiple suppliers. (Moros Adriana, Otero-Palencia Carlos & Paternina Carlos, 2018)	Available on: http://www.ieomsociety.org/paris2018/papers/69.pdf
6	2018	Conference presentation. MIT SCALE Latin America. Boston, Massachusetts, 2018,	A collaborative logistic cost-reduction strategy (S-CJRP) for non-competitive small and medium sized enterprises. (Otero-Palencia & Amaya-Mier 2018)	Presented: 2018/4/16
7	2018	ISI-Q1 Full paper. International Journal of Production Research. Taylor and Francis, England	A stochastic joint replenishment problem considering transportation and warehouse constraints with gainsharing by Shapley Value allocation. (Otero-Palencia, Amaya- Mier & Yie-Pinedo, 2018)	Published:https://doi.org/10.1080/00207543.2018.1526418
8	2019	ISI-Q1 Full Paper, Transportation Research Part A, Elsevier, 2019	A Collaborative Logistical Cost-Reduction Approach for Non-Competitive Small-And Medium-Sized Enterprises: Exploring S-CJRP Coordination and Variability Aspects Through Discrete-Events Simulation. (Otero-Palencia, Amaya- Mier, & Montoya-Torres, 2018)	Acepted by the Editor and under review
9	2019	SCOPUS-Q2 Full paper. Supply Chain International Forum. Taylor and Francis, England, 2019.	Inventory and fleet purchase decisions under a sustainable regulatory environment. (Jaller, Otero-Palencia, and Yie- Pinedo, 2019)	Published: https://doi.org/10.1080/16258312.2019.1664257
10	2019	International Project Proposal. Senate Bill 1 (B1), California U.S.	Development of a Logistics Decision Support Tool for Small and Medium Companies to Evaluate the Impacts of Environmental Regulations in California.	Funds Granted, 80.000 USD. On progress
11	2020	Book Chapter. Emerald Publishing, 2020.	Supply Chain Management and Logistics in Latin America: A Multi-Country Perspective; Chapter 39: Collaborative Inventory Replenishment: Discussions and Insights of a Cost-effective Alternative for Non-competitive Small and Medium-sized Enterprises. (Otero-Palencia, Amaya- Mier, Montoya-Torres, and Jaller 2019)	Accepted for publication. Expected June 2020

Table 1-3: Academic products detached from the research

Project name	Students	Type	Status
Modelo de consolidación de carga contenerizada de empresas del Departamento del Atlántico que importan desde los Estados Unidos.	Odette Yamile Cure Slebi; Raúl Darío Robles Gómez; Wanda Melissa Rodríguez Prada; Andrés Arturo Vargas Bula.	Bachelor Final Project	Concluded 2016
Modelo colaborativo de reaprovisionamiento conjunto estocástico multi-objetivo: reducción de costos, desviación y cash to cash.	Carolay Vanessa Del Valle Reyes; Andrés Arturo Madariaga Ruiz; María Camila Niebles Barrios.	Bachelor Final Project	Concluded 2018
Simulación y análisis del modelo colaborativo de reaprovisionamiento conjunto probabilístico con determinación de agente coordinador.	Elizabeth Ashley Archibold Barrios; Daniela Astrid Blanco Espeleta; María Paula Delgado Racero; Daniela Martínez Álvarez.	Bachelor Final Project	Concluded 2018
Simulación y análisis experimental de un modelo estocástico de reaprovisionamiento conjunto colaborativo en importaciones de Mipymes del Departamento del Atlántico	Kevin Morales Ochoa.	Master Thesis	On process

1.4 Chapter 1 Conclusions

This chapter illustrated the problem that motivated the development of this thesis. In general, Latin American companies face high logistics costs, especially those costs related to international logistics. If the costs of the OECD countries are compared with Colombia and in general with Latin America, it is evident that there are important differences, for example, the Latin American countries spend 3.8 times more money on an export than the OECD highly developed member countries. These OECD members spend only a third of what Latin American countries spend in an import. In general, these high costs threaten the competitiveness of companies in Latin America.

Collaborative strategies have proven to be effective in reducing times, risks, and some of the costs of the supply chain. In this case, a strategy is proposed consisting of the efficient coordination of the replenishment of multiple companies. For this, the author proposed a collaborative inventory model called the S-CJRP that will be introduced later in Chapter 3., and that will be widely discussed and extended in the following chapters. However, before introducing such a model, it is necessary to better understand the characteristics of the inventory replenishment process and what are the cost drivers of such a process, which will be the objective of the next chapter, Chapter 2.

CHAPTER 2. *Practical features of the inventory replenishment decision-making process; A case study in Colombia.*

The purpose of this chapter is to describe the main and real characteristics of the decision-making process when performing an inventory replenishment; it intends to establish a strong link between theory and practice. The chapter first describes the processes involved in inventory replenishment, and, then, proposes a cost structure that allows estimating the actual costs of it. The descriptions of the processes are based on a case study in Colombia. It must be considered that these processes could be substantially different from country to country. However, the characterization strategy process proposed could be replicated in other practical cases.

On the other hand, following the classic approach on supply chain management, the author proposes the cost as the central element of decision-making when replenishing inventory. Subsequently, it proposes a cost structure that intends to be broad enough to cover multiple cases for diverse companies. The author first proposes a set of relevant cost drivers, and secondly, it offers strategies for estimating all related cost elements. Typically, academics in the supply chain management area have focused on designing inventory models for various real situations, as well as their solution strategies, leaving aside the parametrization of such models. Determining logistics costs is not a trivial task, considering the diversity of companies that may exist. The proposed cost structure is a contribution that intends to help to close this gap. There is no similar tool in the literature which gathers the typical cost drivers and estimation strategies for parameterizing inventory models, facilitating the modelers/decision-makers' labor. The importance of this chapter is that the proposed structure becomes the basis for parameterizing the inventory model proposed in Chapter 3, Chapter 4, and Chapter 5. I.e., this structure is a raw material for setting the proposed models in the practice.

The related contributions of this chapter are:

***** The characterization of the typical process involved in the replenishment of inventory, a case study in Colombia.

***** The design of a cost structure to estimate the inventory management costs, including all those related to the inventory replenishment, enabling the estimation of the parameters of cost of the S-CJRP model and related extensions.

A further discussion of the topics covered in this chapter can be found in Henao-Perez, Otero-Palencia, & Amaya-Mier (2018); Otero-Palencia, Carlos; Amaya-Mier (2016); Otero-Palencia, Amaya-Mier, & Borrero (2018) *the main content can be found in the publication R. Amaya et al. (2018) presented next:*

INTERVENCIÓN SOBRE PRÁCTICAS INTEGRATIVAS EN EL CLÚSTER DE LOGÍSTICA DEL ATLÁNTICO

CADENAS LOGÍSTICAS DE COMERCIO EXTERIOR

RENÉ AMAYA MIER
(Compilador)

René Amaya Mier
Rodrigo Barbosa Correa
Alfredo Borrero Paéz
Alvin Henao Pérez
Liyis Gómez Núñez
Saúl González Barranco
Luceny Guzmán Acuña
Adriana Moros Daza
Carlos Otero Palencia
Jorge Oyola Cervantes
Kelly Soto Ching

Área metropolitana
de Barranquilla (Colombia), 2018

UNIVERSIDAD DEL NORTE
Editorial

Published, Jun 12, 2018

2.1 A description of the process of inventory replenishment in Colombia

This section aims to illustrate the typical processes that are carried out by manufacturer and retailer companies when replenishing inventory. A better understanding of these processes allowed us to model the models introduced in Chapters 3, 4 and 5 with greater precision. In other words, it allowed us to bring mathematical models closer to reality.

In this section the approach consists in the development of a practical case, the analysis was made with companies located in the Departamento del Atlántico - Colombia, however, by regulations of the National Government of Colombia, the process must be quasi-standard throughout the national territory. This characterization allows for distinguishing of those processes impacting the logistic cost and their relationships, which is central for designing the cost estimation structure for inventory replenishment presented later in this chapter. Additionally, a better understanding of each of these processes allows a wider vision to determine the feasibility of establishing collaborative practices in the supply chains.

Worth noting is that there are two types of typical replenishment processes; those that involve cross-border processes or imports, and those that do not because the suppliers and products are in the national territory. Henceforth, the former will be referred to as imports and the latter as national replenishment. This work focuses on those processes that involve imports because they are more expensive and in the case of Colombia, they present a low competitive level when comparing with the OCDE countries according to the Doing Business report (World Bank, 2014).

The results presented in this chapter are an extension of the results of the LogPort Research Program (R. Amaya et al., 2018); a research where a representative sample of companies (160) from the Region was taken to improve understanding about foreign trade logistics transactions. The sample included cargo generating companies (manufacturers and retailers), customs agencies, and third-party logistic operators. During the process, interviews were conducted with experts in foreign trade processes, and employees from the purchasing and logistics departments. After fully understanding these processes and measuring their performance using performance metrics, it was possible to characterize the AS-IS (i.e, how it is made) of the inventory replenishment processes in the Departmento del Atlántico for both replenishments implying imports and nationals.

Following the guidelines of the standard logistics model for the typification of the supply chain by SCOR (Supply Chain Council, 2010), three of the five basic supply chain management processes were identified during the interviews with the companies: Plan, Make, Source, Deliver, and Return. This work focusses mainly on the Plan and Source processes, and slightly in the sub-element of the Deliver process known as the Compliance process, since they are involved in the inventory replenishment problem. A short definition of these processes according to the SCOR standard is provided next:

- **Plan:** The processes associated with determining requirements and corrective actions to achieve supply chain objectives.

- **Make:** The process of adding value to products through mixing, separating, forming, machining, and chemical processes.
- **Source:** The processes associated with ordering, delivery, receipt and transfer of raw material items, subassemblies, product and/or services.
- **Deliver:** The processes associated with performing customer-facing order management and order fulfillment activities.
- **Return:** The processes associated with moving material from a customer back through the supply chain to address defects in product, ordering, or manufacturing, or to perform upkeep activities.

As previously mentioned, this analysis focuses on the inventory replenishment activities: source. However, for estimating the cost (costing) of the entire process, planning and delivery activities must also be considered (see Section 2.2). Figure 2-1 describes the observed standard inventory replenishment process, either national or international (those that involve imports). These activities are framed on the source process. It should be noted that national replenishment and import activities follow in principle a similar procedure. However, in the case of imports, an additional agent must be incorporated into the process; often, a third-party logistics licensed as a customs agency. These agencies are authorized by the Colombian Government to serve as intermediaries in the legalization of cargo that enters and leaves the national territory. The process begins with a replenishment signal from either a department related to manufacturing goods, or the sales department after checking over the inventory level. Note that although there could be differences between the nature of the companies, in this case it comes together that at some point a resupply order must be generated. Depending on the size of the company, they may or may not have a purchasing department, however, for practical purposes this department may be understood as the person in charge of purchasing for the company. Then, the company supplier(s) intervenes, regardless of size. Similarly, as for the purchasing department, it proceeds for the finance or accounting department, which is in charge of carrying out the accounting transaction to pay suppliers. As mentioned, depending on whether the resupply involves an import, a customs agency would enter the process. Finally, there must be a logistics department in the company or at least one person in charge of receiving and verifying the merchandise when it arrives at the doors of the company. Sometimes this department is in charge of the purchasing department as well.

Notice again, it is possible that small differences could be present between companies. However, the proposed diagram has all the minimum actors in the process of legalization of cargo in an import. There are some previous negotiations between a supplier and an importer that are developed voluntarily; in these instances, the terms of negotiation to be used must be agreed upon. Once this agreement is reached, an exchange of important documents must be given that guarantee the legality of the transaction. These documents must be provided to the customs agency, given the Colombian customs legislation in force to date[1]. Another important

[1] Decree 2685-1999 (Colombia) - By which the Customs Legislation is modified..

Resolution 4240-2000 (Colombia) - By which Decree 2685 of December 28, 1999 is regulated.

actor/agent is the shipping company used and the destination port, in this case the Port of Barranquilla, who must coordinate the logistics of receiving the cargo that is transported in containers, and the port itself is responsible for giving right of way to the customs authority of Colombia - DIAN - to proceed with the necessary verifications that apply.

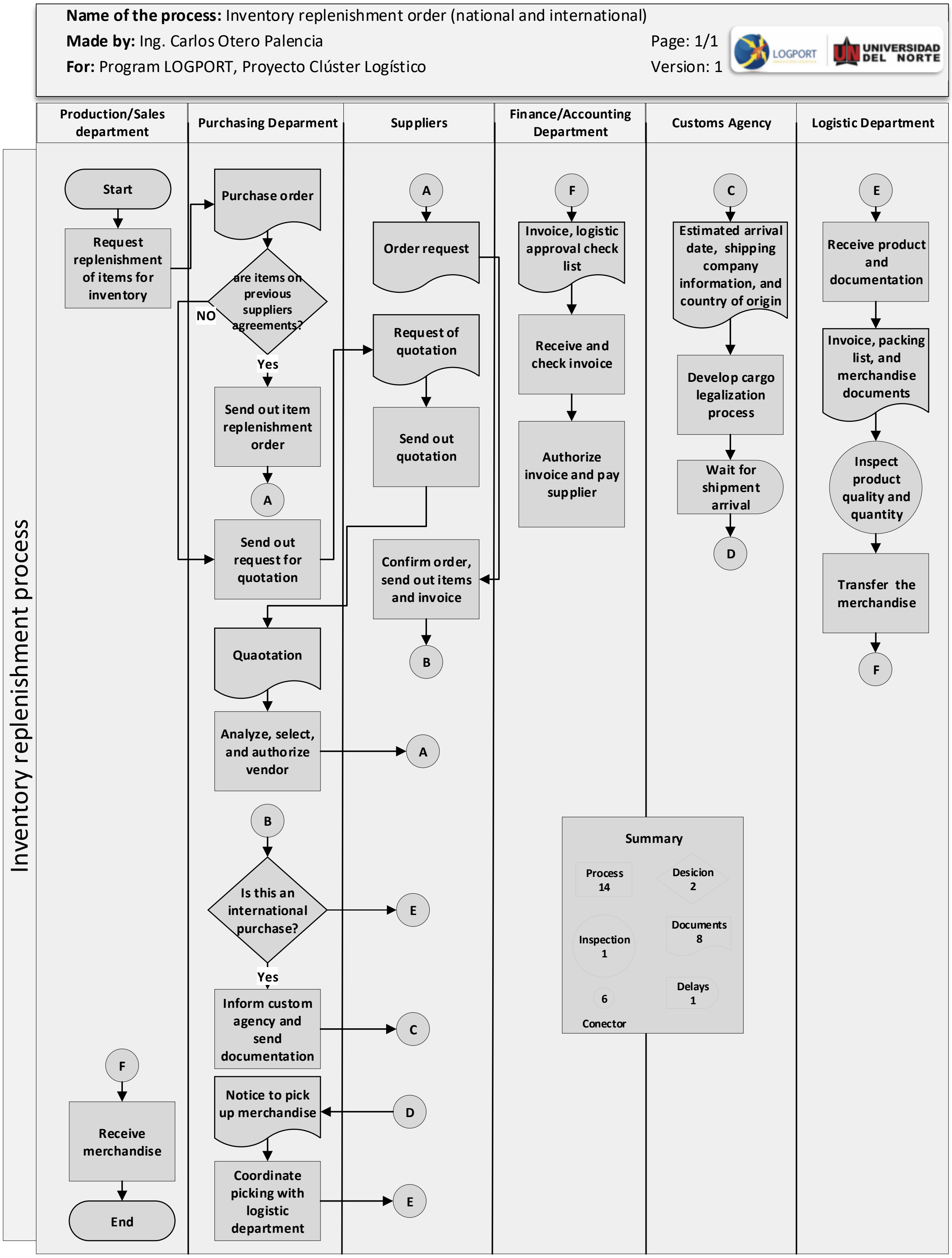


Figure 2-1. Description of typical inventory replenishment process in Colombia

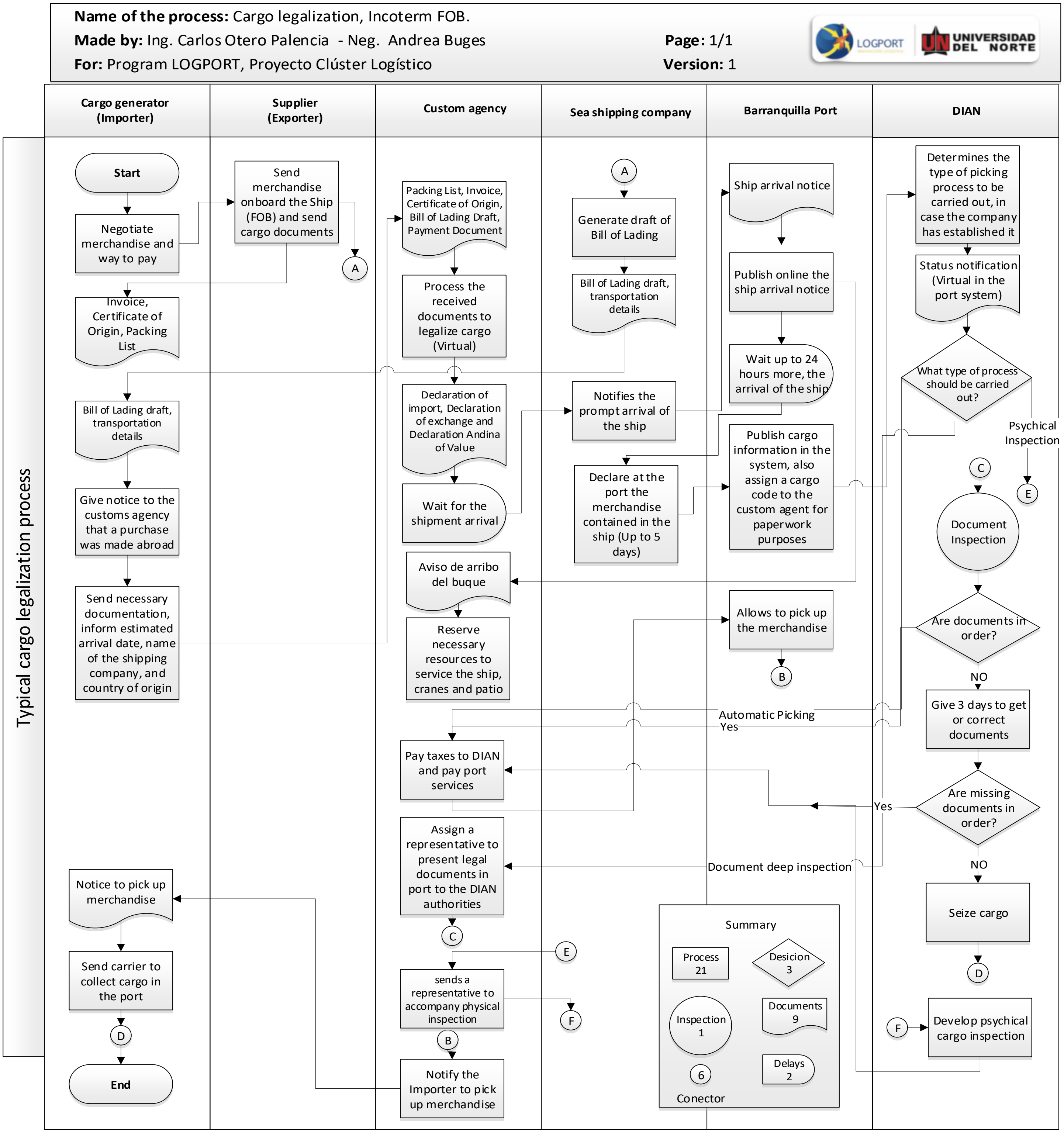


Figure 2-2: Description of a typical import cargo legalization process in the Departamento del Atlántico

The associated planning process for sourcing consists of the development and establishment of courses of action over a specified time of period that represents a projected appropriation of material resources to meet supply chain requirements. This process regularly involves mid-level and upper management in the companies. For large and medium-sized companies it involves the meeting and joint work of directors from departments such as sales, logistics, purchasing, accounting, and even the CEO. For small businesses it could even be carried out by the business owner or person in charge of purchases. The level of planning is divided into long, medium and short term. The short and medium-term planning closely support the operations and supply activities described above in Figure 2-1 and Figure 2-2, while in the long term it is oriented more towards negotiations with suppliers of materials and services. The general process is simple in essence and is presented in Figure 2-3. Planning is basically balancing the requirements of products on sale and the resources available to meet the demand. It is not always feasible to meet all the demands since not all resources are always available or enough. For example, it was observed that companies often have liquidity problems to source raw materials in the required amounts. Also, certain raw materials are sometimes scarce.

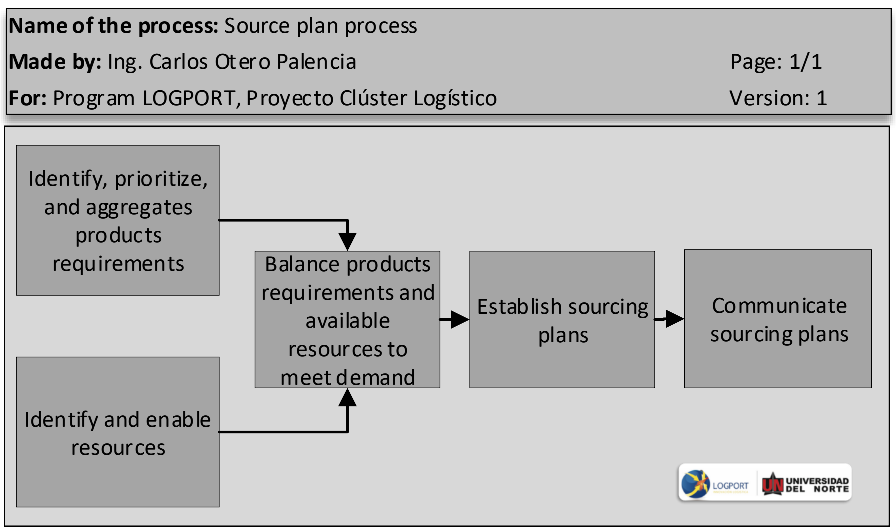


Figure 2-3. Description of typical source planning process in Colombia

Once the planning and sources process are featured the next step is to measure its performance. In the work of R. Amaya et al. (2018), multiple instruments were developed to calculate performance metrics in 3 dimensions: cost, time, and documentation. In this research the cost is of vital importance, the results are summarized in tables presented next. Before introducing such tables, it is necessary to consider some cost elements that are addressed in the analysis. These cost elements are further detailed later in Section 2.2.

- **Labor costs:** These occur by virtue of the time the work team dedicates to activities at different levels, since management to operations for different logistic processes.
- **Automated activities:** Those that originate to support logistic processes based on the use of technology, such as software, licenses, computers, etc.

- **Cost of the use of property, facilities, and equipment:** those that originate in the use of the physical infrastructure of the company and equipment during the logistic work.
- **Inventory cost and risks:** It corresponds to fees related to post-shipment handling or port handling, and any fees paid to a third party that provides services to the cargo.
- **Transportation costs:** Those related to the fees charged by the freight forwarders and third-party logistics for transportation and any related freight service.
- **Fees, taxes, and others:** Those related to fees due to cargo handling, services from third-party logistic operator, fares for sea transportation, and the fees of the customs brokerage companies. Moreover, it also embraces taxes imposed by the government, legal paperwork, and rights fares.

Table 2-1: Summary of the decomposition of the import cost (USD).

Total (T)		Total 1 (T1)		Total 2 (T2)		T2/T1	T2/T
Import	$ 7.171,22	**Planning cost**	$ 1.146,64	**Labor for planning**	$ 696,46	60,7%	9,7%
				Automation planning cost	$ 166,88	14,6%	2,3%
			16,0%	**Cost of facilities and equipment**	$ 283,30	24,7%	4,0%
		Sourcing cost	$ 3.959,66	**Labor for sourcing**	$ 1.033,02	26,1%	14,4%
				Automation sourcing cost	$ 65,06	1,6%	0,9%
			55,2%	**Cost of facilities and equipment**	$ 520,50	13,1%	7,3%
				Inventory cost and risks	$ 2.341,07	59,1%	32,6%
		Cost of material on destination	$ 2.064,91	**Transportation cost**	$ 513,89	24,9%	7,2%
			28,8%	**Fees, taxes, and others**	$ 1.551,03	75,1%	21,6%

Source: (R. Amaya et al., 2018).

Table 2-1 breaks down the total average value of the import cost for all of the samples taken (160), which is subdivided into 3 elements: planning cost, the sourcing cost, and the cost of material at the destination. Each one of these has a series of elements that constitute it, which are indicated in column 5. The cost of planning is associated with the preparatory activities that take place before executing the import, they are carried out between the client and supplier. However, Table 2 shows the costs referring to the client or importer. These elements are made up of the payroll values of the employees involved in the process, the use of facilities, equipment, and software.

The sourcing cost is linked to the activities that are carried out at the time of receiving freight that has been imported by the destination company. These activities again involve labor, the use of equipment, facilities such as warehouses and insurance. On the other hand, the cost of material at the destination is related to transport activities and services related to freight, such as handling, uploading, and downloading. In some companies these activities can occur simultaneously, while in others they turn out to be sequential. The detail of the calculation method is presented in the following section. it should be noted that these developments are expanded in the present research, in order to adapt them to the proposed cost structure.

Table 2-1 also shows that the sourcing cost is the one with the greatest weight, largely due to the impact generated by the inventory cost (including management) and risk, which is also the cost that has the greatest impact on the total cost of importation with 32.6%, followed by fees, taxes, and others with 21.6%. This shows that more than 50% of the import cost is given by the inventory costs of and the cost of the risk, and by fees, taxes, and others. These figures reflect the important impact that inventory ownership brings and its inadequate management. In addition, the high cost that companies must pay for taxes and import procedures in Colombia is evident (21.6%).

Table 2-2: Summary of the decomposition of the export cost.

<table>
<tr><th colspan="2">Total (T)</th><th colspan="2">Total 1 (T1)</th><th colspan="2">Total 2 (T2)</th><th>T2/T1</th><th>T2/T</th></tr>
<tr><td rowspan="9">Export</td><td rowspan="9">$ 1,922.80</td><td rowspan="3">Planning cost</td><td rowspan="2">$ 454.06</td><td>Labor for planning</td><td>$ 407.41</td><td>89.7%</td><td>21.2%</td></tr>
<tr><td>Automation planning cost</td><td>$ 88.8</td><td>2.0%</td><td>0.5%</td></tr>
<tr><td>23.6%</td><td>Cost of facilities and equipment</td><td>$ 37.77</td><td>8.3%</td><td>2.0%</td></tr>
<tr><td rowspan="6">Compliance cost</td><td rowspan="3">$ 1,468.74</td><td>Transportation cost</td><td>$ 205.30</td><td>14.0%</td><td>10.7%</td></tr>
<tr><td>Fees, taxes, and others</td><td>$ 463.01</td><td>31.5%</td><td>24.1%</td></tr>
<tr><td>Automation compliance cost</td><td>$ 17.74</td><td>1.2%</td><td>0.9%</td></tr>
<tr><td rowspan="3">76.4%</td><td>Labor for compliance</td><td>$ 319.81</td><td>21.8%</td><td>16.6%</td></tr>
<tr><td>Cost of facilities and equipment</td><td>$ 34.04</td><td>2.3%</td><td>1.8%</td></tr>
<tr><td>Inventory cost and risks</td><td>$ 428.84</td><td>29.2%</td><td>22.3%</td></tr>
</table>

Source: (R. Amaya et al., 2018)

In order to compare the cost elements of the import and export process, Table 2-2 indicates that more than half of the export cost is caused by the cost of compliance, while the lower is the cost of planning. However, when the individual components are analyzed, the one with the greatest impact is the cost of fees, taxes, and others: 24.1%. Once again, the cargo and tax legalization processes become the most important element of the total cost. The next element is the inventory cost (again, including management) and risk with 22.3%. It seems that inventory cost is the same as in the case of imports, an element that could be improved with better management. Next, there is the labor cost of planning with 21.2%, which indicates that the labor employed in these processes turns out to be significant.

The foregoing shows that fees, taxes, and others significantly impact the costs of companies' foreign trade operations, with an average value of 22.9%. Another common element is the high impact that inventory cost and risk have on the structure, showing a great opportunity to develop reengineering processes, considering that inventory management is under the control of the companies, unlike state-dependent tax costs.

The sample taken included companies from various sectors: construction, agribusiness, technology, textiles, heavy machinery, and auto parts, etc. Taking into account that in this research, a case study was carried out in the auto parts industry, the summary of the results of the samples taken is presented, together with other industries that import by sea, such as the textile and heavy machinery. The information is summarized in Table 2-3.

Table 2-3: Classification levels for the Cost (USD) and import time (days) for the textile industry, auto parts, heavy machinery, and construction.

Attribute	Metric	Deficient		Average		Superior		Excellent	
Cost	Planning cost	$ 5,231.84	$ 1,741.00	$ 1,741.00	$ 449.35	$ 449.35	$ 102.45	$ 102.45	$ 4.81
	Sourcing cost	$ 18,745.4	$ 4,987.69	$ 4,987.69	$ 1,846.2	$ 1,846.2	$ 1,057.9	$ 1,057.9	$ 40.83
	Cost of material on destination	$ 8,444.49	$ 2,473.85	$ 2,473.85	$ 1,354.8	$ 1,354.8	$ 706.00	$ 706.00	$ 17.31
Time	Process time	100.00	90.00	90.00	48.00	48.00	30.00	30.00	9.00

Source: (R. Amaya et al., 2018)

The previous table classifies the results of 34 companies from the aforementioned industries into quartiles. It is observed that the costs of supplying are the most important, as observed in the summary presented in Table 2, followed by the cost of planning, where labor cost is the most important element. In general, these costs have a considerably high range of variation. For example, the sourcing cost ranges from $ 40.83 in the quartile that contains the top 25% to $ 18,745.4 in the bottom 25%, a range of $ 18,704.57 with an approximate deviation of $ 9,352.2, evidencing the great diversity of cases in the Region. The companies of interest for this research are those with high costs. For example, those that are in the lower or poor quartile are the average since they are expected to have significant opportunities to develop reengineering processes. Regarding the import process time, the range is also wide: 91 days. This shows that there are companies with highly efficient processes. The time considered begins with the merchandise quotation process and ends when the cargo is available at the buyer's facilities. Shipping time is excluded, since it depends on the geographical location supplier and not import management.

After having analyzed the cost parameters for each of the activities related to the foreign trade processes in the companies that were part of the research and considering the appreciations of (R. Amaya et al., 2018), it is possible to conclude the following:

This section has exposed the elements and activities that are part of the replenishment of inventories, as well as regular times and the internal documents and the mandatory legal documents for companies that intend to resupply both nationally and internationally. It was also indicated that in this research, replenishment processes implying imports are the focus of attention because they are more expensive and apparently less competitive if compared to OECD countries (See Section 1.1.1). The cost metrics are intended to calculate the cost of the operations involved in the import process at a mainly global level. However, these metrics are insufficient to detail all the existing cost elements in a replenishment process; even less to parameterize a decision-making model that allows determining the frequency and optimal size of a replenishment. In the next section, a cost structure will be presented at a higher level of detail, which will allow the basic parameterization of inventory models for decision-making.

2.2 Inventory replenishment cost estimations

In this section a cost structure is introduced that offers a high level of detail; considering all the processes observed in practice and those recognized in the literature. This cost structure will be useful for practitioners working with inventory models like those introduced later in Chapters 3 and subsequently in Chapter 4 and Chapter 5. One of the advantages of this proposed structure is that it was tested and proved to work in practice in more than 160 cases, and it could be expanded and adapted to other essentially similar models.

There are two well-known fundamental cost elements for estimating the inventory replenishment cost: the ordering cost and the holding cost. The former is directly related to the required activities to request and receive a replenishment order, while the second considers the cost elements required for storing and keeping cargo (Ballou, 2004). However, in the literature, cost structures to estimate these costs are scarce. Typically, authors are limited to indicating only the cost drivers, but not cost estimation methods. Central authors in this topic such as Chopra & Meindl (2013) and Ballou (2004) relate several cost drivers to the ordering cost: administration costs, three-party logistics operators fees, cargo equipment rent, and any handling cargo expense (such as cargo reception). On the other hand, common cost drivers for holding inventory are those related to warrant the cargo integrity and the opportunity cost related to the cost of capital retained in the inventory investment. These costs are for example salaries of security service, insurances, management costs, shelves rent/purchase, and special accommodation expenses, among others (Silver, Pyke, & Peterson, 1998; Simchi-Levi, Kaminsky, & Simchi-Levi, 2003).

Overall, according to the knowledge of the author, no primary or secondary information source offers a complete structure/method for estimating the inventory replenishment costs. A similar concern was stated in the research carried out by (Amaya et al., 2017). Consequently, one of the contributions of this research is to gather and provide a robust and consistent structure to estimate all the cost elements inherent to the inventory replenishment problem since it is non-existent.

2.2.1 Ordering costs

As mentioned earlier in this section, the costs incurred when ordering an inventory replenishment are associated with the expenses of administrative processes, third-party services, and the purchase of supplies or materials. Classifying the relative importance of these costs is essential when interested in benchmarking the logistic operations performance either at the business level or at the national level. Even more during the reengineering process.

A central reference that allows the benchmark between different types of costs associated with logistics processes is the World Bank's Doing Business (Banco Mundial, 2007). Doing Business aims to determine the ease of doing business in 189 world economies and evaluating different processes related to the economy of a nation. For example, the ease of opening of companies, payment of taxes, and property registration, etc. Doing Business provides a database that allows understanding, analyzing, and contrasting information about the rules that regulate business activity. One of the sections, Cross-border trade (World Bank, 2016) includes measurements in terms of time, costs, and documentation as the fundamental elements to measure the performance of supply chains. In this research, the surveys and methodologies used by Doing Business were considered to carry out its measurements, and as a starting point for the developments necessary to carry out the objective of developing a robust and comparable cost structure.

Despite that Doing Business indicates the general elements to estimate costs of the processes related to an import, it does not provide enough operational detail and why it was necessary to complement the information with the model proposed by the Supply Chain Council through the model known as SCOR®, since it discriminates all the activities related to the supply process of a company and the relations with the contiguous links of the supply chain to which it belongs.

SCOR is widely accepted in the industry. It proposes an application method that can be very extensive, but quite rigorous, facilitating comparability and flexibility. It also proposes a series of multilevel metrics, starting from the operational to the tactical level that facilitates the measurement of various variables, time, flexibility, cost, and reliability. SCOR has a useful generic modeling scheme to understand the relationships between nodes in a supply chain (Supply-Chain Council, 2008).

Aiming to corroborate and contrast all the cost elements of the supply processes proposed by SCOR, and those inherent in the typical import processes in Colombia, they were compared with those proposed by the SCOR methodology and those proposed by Procolombia (2015) in its International Physical Distribution –DFI- model. These resulting elements are summarized in Table 2-4.

Table 2-4: Resulting accounting costs related to the import process, adapted from Procolombia 2015 and the SCOR 9.0 model.

ACCOUNTING COSTS OF IMPORT	
CONCEPT	**COST DRIVER**
Handling Upload/ Download	Labor, equipment rent (Cranes, hoists), Complementary services

ACCOUNTING COSTS OF IMPORT	
Holding	Download and handling, equipment rental, warehouse rent, product losses
Transportation from boarding point to the warehouse	Transport fee, insurance policy value according to Incoterms, bank commission according to means of payment, customs commission
Agents	Cargo agents commission, inspectors Commission, shipping related costs, documentation
Management	Management costs, capital cost, cost in inventory

It is noted that some of the costs in the previous table were confirmed through interviews with customs brokerage companies and importers.

The proposed definitive structure is presented in Table 2-5. Each of the elements consigned is detailed below.

Table 2-5: Proposed ordering cost estimation structure.

ORDERING COST ESTIMATION STRUCTURE
PLAN
Labor planning cost
Automation planning cost
Cost of facilities and equipment
SOURCE
Labor sourcing cost
Automation sourcing cost
Cost of facilities and equipment
Transportation cost
Fees, taxes, and others

2.2.1.1 Costing of the planning process

According to Olarte Fiorillo (2011), the planning process must consist of an evaluation of the available resources and subsequently a balancing of the percentage of demand able to be covered (customer orders) with the given resources. This applies to sales inventory, production, and distribution plans; often synchronized when companies are manufacture based. The execution of each of the supply chain processes is sensitive to proper planning, which is why planning must be based on reliable data and for objectives with fixed time horizons. In general, planning consists of determining what the ability is of the companies to satisfy demand objectively. Insufficient planning triggers in process disruptions by a lack of resources.

In general, senior managers must implement, short, mid, and long-term plans, goals, and policies. Short term plans are involved in the day to day operation. Mid-term plans often involve a month's time frame or similar. Long-term plans are based on companies' competitive strategy, which provide guidelines for the choice of the products or services that should be outsourced or insourced and which markets must be prioritized (Rayburn, 1999). These planning levels are discussed next.

Among the costs examined in the planning, taken from the SCOR methodology, we detail those involved in the following activities:

- **Labor for planning:** This occurs by virtue of the time the work team dedicates to the process of planning foreign trade activities.

The supply chain planning process tries to answer the questions of what, when and how; and it takes place at three levels: strategic, tactical and operational. According to Ballou (2004), ***strategic planning*** is considered long-range when the time horizon is greater than one year; this works with very general information, which is incomplete and imprecise. ***Tactical planning*** involves an intermediate time horizon, usually less than a year. And ***operational planning*** is a short-range level of decision making, with decisions that are often made on an hourly or daily basis; This, unlike strategy, works with more accurate information than is currently available.

For the development of the planning cost methodology, the attention is directed to planning at the tactical level, since the interest focuses on the best decisions of the same tenor.

The cost inductors in this case are:

- Total payroll of executives involved in the planning process
- Time dedicated to the planning process, regarding the planning of both local and abroad sales and purchases of supplies.

Expression in (2-1) serve for calculating the planning cost.

$$\begin{aligned} \mathit{Labor\ planning\ cost} \\ &= \mathit{Payroll\ of\ executives\ involved\ in\ the\ planning\ process} \\ &* \ \mathit{Time\ spent\ in\ the\ process} \end{aligned} \tag{2-1}$$

- **Automated planning activities:** Those that originate to support the planning process based on the use of technology for the time involved in the process.

Cost drivers are:

- Annual amortization of Enterprise Resource Planning (ERP) software or similar.
- Technical service or annual update

Other considerable drivers are:

- Dedicated time to the planning process
- Amount of licensed computers
- Amount of computers used in the process

Next, expression (2-2) allows calculating the costs of planning automation.

$$Automation\ planning\ cost = \left(\frac{Annual\ amortization\ of\ the\ ERP\ +\ Annual\ technical\ service\ for\ the\ ERP}{Number\ of\ licensed\ computers}\right) * (Number\ of\ computers\ involved\ in\ the\ process) * (Time\ fraction\ spent) \quad (2\text{-}2)$$

- **Activities of the use of Property, Plants, and Equipment:** those that originate in the use of the physical infrastructure of the company.

  Cost drivers are:

  - Annual depreciation of plants and equipment used in the process

  Other important drivers are:

  - Dedicated time to the planning process
  - Number of company employees
  - Number of employees dedicated to the process

The expression (2-3) allows calculating the cost of the use of property, plants, and equipment.

$$Cost\ of\ facilities\ and\ equipment\ (Plan) = \left(\frac{Annual\ depreciation\ of\ plant\ and\ equipment\ used\ in\ the\ process}{Number\ of\ company\ employees}\right) * (Number\ of\ employees\ dedicated\ to\ the\ process) * (Dedicated\ time\ to\ the\ planning\ process) \quad (2\text{-}3)$$

2.2.1.2 Costing of the sourcing process

Valencia (2011) classifies inventory-related costs (products to be imported) into three groups. The first group is known as the order cost (CP) and refers to the costs associated with acquiring inventory. Examples of this first group include the following:

• Costs of operating a purchasing office
• Payroll of the purchasing department

• Calling service
• Stationery
• Quotes
• Depreciation of the office equipment
• Transportation costs

The previous costs are seen in each of the activities involved in the import process. These are detailed in the following activities:

- **Labor for sourcing:** That occurs by virtue of the time the work team dedicated to the sourcing of supply.

Cost drivers are:

- The payroll of the purchasing department and others involved in the supply process.

Other drivers to consider when estimating the cost:

- Time dedicated to the purchase process

Expression in (2-4) represents the sourcing costs:

$$Labor\ sourcing\ cost = The\ payroll\ of\ the\ purchasing\ department * Time\ dedicated\ to\ the\ purchase\ process \quad (2\text{-}4)$$

- **Automated sourcing activities:** Those that originate to support the import process based on the use of technology for the time involved in the process.

Cost drivers are:

- Annual amortization of the ERP
- Technical service and/or annual update

Complementary cost drivers to consider when determining the cost:

- Time dedicated to the sourcing process
- Total number of licensed computers

The following expression in (2-5) is proposed to calculate the cost of automation of the sourcing:

$$Automation\ sourcing\ cost\ (Source) = \frac{Anual\ amortization\ of\ the\ ERP\ +\ Annual\ technical\ service\ for\ \ the\ ERP}{Number\ of\ licensied\ computers}) * (Number\ of\ computers\ involved\ in\ the\ process) * (Time\ fraction\ spent) \quad (2\text{-}5)$$

- **Activities of the use of Property, Plant and Equipment**

Those that originate in the use of the physical infrastructure of the company.

The cost drivers in this case are:

- Depreciation of the equipment of the purchasing department.

Complementary cost drivers to consider when determining the cost:

- Time dedicated to the sourcing process
- Total number of company employees
- Number of employees dedicated to the process

$$Cost\ of\ facilities\ and\ equipment\ (Source) = \left(\frac{Annual\ depreciation\ of\ plant\ and\ equipment\ used\ in\ the\ process}{Number\ of\ company\ employees}\right) * (Number\ of\ employees\ dedicated\ to\ the\ process) * (Dedicated\ time\ to\ the\ sourcing\ process) \quad (2\text{-}6)$$

- **Transportation cost**

This cost is related to the fees charged by the freight forwarders and third-party logistics. The items included are not restricted to freight transportation, but also to related services, such as:

- Unitarization
- Upload
- Download
- Disaggregation
- Sea freight
- Ground freight
- Packaging

Transportation cost is divided often into two categories: origin and destination transportation costs. Third-party logistic operators typically charge several concepts/fees in a single invoice such as packaging, unitization, loading, and sea transportation.

On the other hand, downloading costs, unbundling, and land freight are charged at the destination. The cost driver, in this case, corresponds to the carrier's rate per trip.

For cases where the Free On Board (FOB) incoterm (trade term) is used, the cargo responsibility and cost is guaranteed to the boarding of a ship (determined by the buyer). It was found that the FOB incoterm is the most often used, which features zero cost for transportation at the suppliers' expense and is the buyers' responsibility.

- **Cost of fees, taxes, and others.**

This corresponds to fees related to post-shipment handling or port handling, and any fees paid to a third-party that provides freight services. The value of the sea freight and the fee of the customs brokerage companies is included within this category. Furthermore, this concept includes taxes imposed by the government and any expense due to the legalization of cargo or any legal paperwork.

2.2.2 Holding cost

Inventory holding cost is incurred just by giving entry to an item family into a warehouse. The holding cost can be divided into two elements: financial costs related to the opportunity cost of having money invested in stock and the operating cost of ensuring the integrity of the inventory (Chopra & Meindl, 2013). Table 2-6 summarizes the proposed structure to estimate the cost of maintenance, the elements recorded in it are discussed below.

Table 2-6: Estimation structure for holding cost

Cost estimation structure
Capital cost
Obsolescence cost
Cost of risk
Occupancy cost
Inventory management cost and miscellaneous

2.2.2.1 Capital cost

This corresponds to the more significant cost in the holding cost concept. The method suggested in the literature is to evaluate the weighted average cost of capital (WACC). WACC takes into account the expected rate of return of the company's capital and the cost of its debt (Ballou, 2004; Chopra & Meindl, 2013). The proposed formula is as follows:

$$WACC = \frac{E}{D+E}\left(R_f + \beta * MRP\right) + \frac{D}{D+E} R_b (1-t) \qquad (2\text{-}7)$$

Where

E	*Capital costs*
D	*Amount of debt*
R_f	*Risk-free rate of return*
β	*Betha or the company risk*
MRP	*Market risk prime*
R_b	*Rate at which the company borrows money*
t	*Tax rate*

WACC is usually available in the company's financial annual report, or in capital investigation reports. The loan rate comes from tables that contain the rates charged for bonds of companies with the same credit ratings. The risk-free rate is the return on government certificates, and the market risk prime is the market return above the risk-free rate. When there is no access to the companies' financial structure, a good approximation is achieved by using the figures of public companies from the same industry and of similar size.

2.2.2.2 Cost of obsolescence or deterioration

This concept is related to the rate at which the book value of the stored product decreases because of the market value or quality decrease. By nature, some products have a higher rate of obsolescence. For example, perishable products, or in the case of Christmas decorations; those which reach a higher price near the Christmas season, but which lower their value once this happens. There are also products with a very low obsolescence rate, such as oil. To estimate this loss, it is as simple as calculating the item's book value at the beginning of the accountable period minus the decrease or deterioration at the end.

2.2.2.3 Cost of the risk

Costs of the risk are those that originate with the purpose of keeping inventory integrity. According to Valencia (2011), the control and management of inventories include the handling, security, and storage of merchandise. In this case, considered only are those costs related to warrant the integrity of the inventory.

Cost drivers in this case are:

- Comprehensive insurance of the company
- Payroll of surveillance
- Other security expenses

Complementary cost drivers are:

- Total ground area of the company
- Ground area for inventories

$$Cost\ of\ risk = \left(\frac{Comprehensive\ insurance\ cost + Payroll\ surveillance + Other\ security\ expenses}{Ground\ area\ for\ inventories}\right) * Total\ ground\ area\ of\ the\ company \quad (2\text{-}8)$$

2.2.2.4 Inventory management cost and miscellaneous

This concept is related to the value of the payroll of the people whose task it is to manage the inventory, such as warehouse coordinators, supervisors, and others. Likewise, the rental cost or depreciation of equipment related to the management activity and the materials that may be required.

Cost drivers in this case are:

- The payroll of the warehouse team and managers
- Rent of equipment
- Cost of materials: pallets, ribbons, ropes, etc.

$$= Warehouse\ team\ payroll + Rent\ of\ equipment + Cost\ of\ materials \quad (2\text{-}9)$$

2.2.2.5 Occupation cost

Corresponds to the cost of renting warehouses or areas intended for storage of inventory. In the event that the warehouses are their own, the value of the rent of warehouses of similar characteristics should be considered as an opportunity cost. The cost driver is the warehouse are allocated to store inventory.

2.2.2.6 The "h" fraction

The cost to holding inventory is represented by “h”, which can be represented in two ways: as a fraction of the unit cost, or as the unit cost of holding inventory in units $ /unit/year. In any case, it is calculated considering the cost for obsolescence, capital cost and the other elements detailed in Table 7. The *h* value considered in this case corresponds to the unit cost for annual holding, and it is calculated using the following expression:

$$h = \frac{Total\ annual\ holding\ cost}{Actual\ annual\ demand} \quad (2\text{-}10)$$

2.3 Chapter 2 final remarks and considerations

The developed structure aims to estimate a set of unknown costs at a high detail level. It provides useful information, that is true and reflects reality. There is no report in the literature that fully provides a structure for estimating the ordering and holding costs and their cost drivers and estimation strategies.

The proposed structure is essentially an extension of the results of a previous research carried out in the Proyecto Cluster Logístico attached to LogPort*:* (R. Amaya et al., 2018), a project of which of the author of this research was part. It was validated that each of the cost drivers reflects the actual nature of foreign trade processes. A comparison pattern is not available to validate the results obtained, so the validation was made through interviews with experts in customs intermediary companies, third-party logistics, and some cargo generator companies. These experts made remarks and suggestions that allowed for improvement of the structure and its estimation strategy.

It is recognized that the information has some degree of imprecision due to the estimated nature of the data and the eventual subjectivity of the respondents. However, as a guarantee of validity, the process was carried out systematically and in a standard way by the main author. The results are not comparable with the base methodologies taking into account that in this case the concerns were made very close to the processes and *in situ*, in small, medium and large companies. In this sense, the author leans on the strategy used by Doing Business and LPI since the 1990's (Doing Business, 2016; World Bank, 2007). The World Bank contracts well-known non-governmental entities as a guarantee of transparency and to avoid any bias. As in the case of this research, the results are supervised by a series of experts, who are part of the design process through their annotations. Like Doing Business and LPI, they are based on assumptions such as the transparency of the respondents, knowing their suitability, the criteria of experts and businessmen with a track record as truthful information.

This chapter served to better understand the decision-making processes developed typically when replenishing inventory, including those related to international logistics, in this case, those commonly carried out in Colombia. In addition, a cost structure was developed that serves to parameterize the inventory models that will be introduced later in this document. In the next chapter, Chapter 2, it will be introducing the central inventory model of the thesis; the S-CJRP model.

Mediante un modelo de simulación se evaluaron múltiples escenarios

CHAPTER 3. *A Stochastic Joint Replenishment Problem Considering Transportation and Warehouse Constraints with Gainsharing by Shapley Value Allocation*

The purpose of this chapter is to introduce a heuristic approach that uses a capacitated inventory model as means for identifying a collaborative agreement between different buyers jointly replenishing multiple items from multiple vendors, thus attaining economies of scale while reducing by sharing fixed procurement and operational costs. The proposed approach is denominated Stochastic Collaborative Joint Replenishment Problem (S-CJRP) and consists of two stages. The first stage determines a cost-efficient replenishment frequency for each collaborating company in all possible coalition arrangements. To accomplish the former, an extension of the known Joint Replenishment Problem (JRP) considering real-life capacity constraints, such as stochastic demand assuming normal distribution, finite storage and transport, is solved via genetic algorithms delivering a suitable coalition. In a second stage, the Shapley Value function is established to assess and allocate the potential gains achieved by colluding in the first stage, determining a fair share distribution among players that increases the viability of such coalition. Several scenarios from a simulated numerical study illustrate average cost savings of 32.3%. 28.2% and 32.7% for 3, 4 and 5 players respectively, considering up to 30 items for the proposed collaboration, in all cases consistently exhibiting cost reduction and increasing the proposal feasibility.

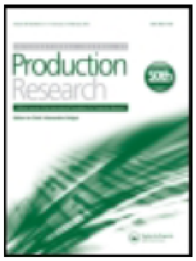
The related contributions of this chapter are:

***** The introduction of a novel extension of the JRP named the S-CJRP, which deals with stochastic demand, non-zero lead times, multiple items and buyers, finite warehouse and transport capacities. This set of features is commonly found in practical settings, but they have not been reported before.

***** The introduction of a novel eclectic heuristic approach that uses the S-CJRP model as means for identifying a collaborative agreement between different buyers jointly replenishing multiple items from multiple vendors, thus attaining economies of scale while reducing by sharing fixed procurement and operational costs.

***** The improvement in the understanding about how to exploit the S-CJRP potentials and the formulation of policies regarding coalition member selection to increase benefits and facilitates surplus allocation through the analysis of experimental settings for a variety of players with different features.

The current chapter is based on the publications; Daza, Otero, & Paternina (2018); Otero-Palencia, Amaya-Mier, & Yie-Pinedo (2018); Otero & Amaya, 2017)*. However, the central work is the next:*



Taylor & Francis

International Journal of Production Research

ISSN: 0020-7543 (Print) 1366-588X (Online) Journal homepage: http://www.tandfonline.com/loi/tprs20

A stochastic joint replenishment problem considering transportation and warehouse constraints with gainsharing by Shapley Value allocation

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To cite this article: Carlos Otero-Palencia, René Amaya–Mier & Ruben Yie-Pinedo (2018): A stochastic joint replenishment problem considering transportation and warehouse constraints with gainsharing by Shapley Value allocation, International Journal of Production Research, DOI: 10.1080/00207543.2018.1526418

To link to this article: https://doi.org/10.1080/00207543.2018.1526418

Published online: 28 Sep 2018.

Published September 28, 2018

3.1 Introduction

Chapter 1 illustrated the administrative and decision-making processes that are carried out in practice when developing an inventory replenishment, as well as, it was introduced a structure to parameterize the costs elements of inventory models such the joint replacement problem (JRP) and the one core of this thesis that will be introduced in this chapter; the Stochastic Collaborative Joint Replenishment Problem (S-CJRP). The current chapter illustrates the theoretical background of the JRP. A historical account of the problem is provided through a review of the state-of-the-art of both the problem formulation and its solution strategies. Then the model S-CJRP is introduced and positioned. Finally, exhaustive tests are developed to validate its usefulness.

The JRP is concerned with coordinating the ordering of several items, commonly from a single supplier. This effort is justified because of the savings that could be achieved from both ordering and inventory holding costs. By definition, such savings from group replenishment are more significant than the largest individual ordering cost (Khouja & Goyal, 2008). Furthermore, the transportation cost per unit could decrease as well, because of the improved use of space from aggregated shipments.

The JRP has been studied for more than 50 years, since the early work of Miller and Starr (1962). The major part of the available literature focuses on solving the JRP efficiently. Several procedures and improvements has been proposed along this way (Aksoy & Erenguc, 1988; Eijs, Heuts, & Kleijnen, 1992; Fung, Ma, & Lau, 2001; S. K. Goyal & Deshmukh, 1993; Hariga, 1994; Kaspi & Rosenblatt, 1983; Nocturne, 1973; Silver, 1976; Viswanathan, 1996, 2002). However, the methodologies that provide with the best performance are the RAND solution procedures (Kaspi & Rosenblatt, 1991) and genetic algorithms (Khouja, Michalewicz, & Satoskar, 2000a; Olsen, 2005). Genetic Algorithms (GAs) produces better solutions to the JRP than RAND for some problems and can almost match the performance of RAND from a practical point of view for the rest of the problems. GAs never converged to a solution with a total cost of more than 0.08% of the total cost obtained from RAND for 1600 randomly generated problems, as proved by Khouja, Michalewicz, and Satoskar (2000). Although the JRP is characterized by being a more practical model than the classic EOQ, some of its classical assumptions are debatable. The problem has been extensively studied as an unrestricted problem. Yet, in practice there are many resource constraints (i.e., transportation budget and storage capacity) neglected in most of the previous literature, as discussed in section 3. In another hand, the demand has been extensively considered as a deterministic variable when in most actual setting is indeed stochastic. In addition, shortages are regularly not allowed, and quantity discounts are no available.

This chapter is concerned with a practical inventory situation in which a group of non-competing buyers companies, henceforth coined as players, agree to cooperate in order to share and allocate fixed costs of a joint and coordinated replenishment by means of the Shapley function. We define a JRP extension, considering normal demand and multiple buyers jointly replenishing multiple items from multiple vendors with finite storage and transport capacity, denominated as Stochastic Collaborative Joint Replenishment Problem (S-CJRP). The ‘Collaborative’ word used in the acronym title responds to its extended scope to provide with an enhanced solution which allocates surplus benefits among all players (i.e.: savings) proportional to the marginal contribution of each player to the total cost reduction of the proposed coalition, accomplished by the explicit and agreed recognition of the Shapley Value function (Shapley, 1953) as a suitable allocation method among the players. Under our S-CJRP, the original coalition of N members remains unchanged; therefore, we cannot warrant the optimal coalition. Furthermore, our scope does not intend to guarantee stability in the sense of the core, since we are using the Shapley Value function because of its valued sense of fairness and formality, offering a unique allocation in compliance with Shapley axioms (Dror & Hartman, 2011). Nonetheless, our approach would not only reduce the ordering and inventory costs of all players but provide a fair surplus allocation in the sense that any given participant would obtain shares from the coalition that are proportional to her investment.

JRP is a classic in the literature, and some of the practical settings dealt with by the proposed S-CJRP, such as stochastic demand, multiple items and vendors, non-zero lead times, finite warehouse and transport capacity, had been individually considered in the literature, as exposed in section 3. Yet, we pose that our work is the first to concurrently treat such particular combination of assumptions which are commonly found in practical settings and contributes to extend the scope of both current JRP theory and application. In addition, through a case study that uses a preliminary version of our model, we have shown that our S-CJRP could generate potential savings compared to the traditional method of individual replenishment (Otero & Amaya, 2017). However, in the present work the scope is notably extended through more practical assumptions, an efficient solution method and we develop an exhaustive test procedure in order to prove his effectiveness.Under this practical extension it is possible to derive a logistics cost reduction out of a coordinated (through the collaborative strategy) ordering from a finite number of buyers by means of a capacitated JRP. However, it is non-trivial task to determine the former cost reduction allocation amongst the players. There could be asymmetric individual contributions to cost reduction due to different players. Since players are in need to incur in coordination and shared operational costs for colluding, we argue that an impartial cost allocation for the coalition is necessary and should be one coherent with the individual average contribution, which explains our choice of use of the Shapley Value function. Moreover, such allocation would in turn increase feasibility and likelihood of acceptance of the proposed coalition and collaborative arrangement, since the individual players' perception of fairness and return over investment of such arrangement granted by Shapley is prerequisite for the overall agreement on the coalition. Thus, S-CJRP enables not only to attain simple cost reduction as in JRP, but moves on to deliver a viable solution that overcomes a frequent barrier oftentimes present in actual collaborative efforts (Hartman & Dror, 2003; Nagarajan & Sošić, 2008) such as mistrust or suspicion. Because of the former, we posit as our main contribution an eclectic heuristic approach (S-CJRP) that takes as means extant approaches from inventory theory, optimization and cooperative games, seamlessly interacting and complementing to deliver viable solutions to more realistic collaborative settings.

The purpose of this chapter is to illustrate both the method and the benefits arising from S-CJRP. The structure is as follows: Section 3.2 presents the problem description and the supply chain schema. Section 3.3 introduces the model. Section 3.4 deals with the solution method, and Section 3.5 delivers numerical instances to exemplify collaboration benefits. Finally, in Section 3.6, discussion and conclusions are summarized.

3.2 Problem description and proposed logistics schema

The replenishment of items may mean large ordering and holding inventory cost for many buyers. For example, imports (procurement) costs may include a large amount of fixed and variable components per transaction, such as the cost of freight rates, port charges, 3PL fees, cargo handling, bank charges, etc. From a single company economical perspective, such a large ordering cost forces higher order quantity that in turn poses additional costs due to warehouse space and inventory management since the orders would normally exceed demand. For companies with both limited budget and logistical resources the situation is even worst, since could be desirable but non-viable to increase the order quantity to achieve scale. Therefore, it follows that there is a large number of practitioners in several business settings for which it remains as a relevant issue how to increase or maintain cargo size at economical quantities and simultaneously keep inventory costs under control.

In such conditions, joint replenishment of cargo among several importers could make sense since constitutes a trade-off between reducing ordering and inventory costs while maintaining an economical (joint) cargo size, but at the expense of additional coordination costs. Indeed, supply chain collaboration has been extensively established as a source of cost reductions in the literature (Holweg et al. 2005; Stank, Keller, and Daugherty 2001; Barratt 2004; Horvath 2001; Simatupang and Sridharan 2002; Skjoett-Larsen, Thernøe, and Andresen 2003), out of which there is a significant opportunity for sharing the additional benefits or surplus from collaboration among collaborating parties (Defryn et al. 2013; Kelley and Hounsell 2007; Vanovermeire et al. 2014). Yet, collaboration between different parties involves additional problems that come with the supplementary benefits: in the short-term, developing an investment and surplus fair allocation agreement; from a longstanding perspective, achieving sustainable acceptance of the former agreement from diverse parties (see Section 3.4.3). A fair allocation of the cost in a coalition should be one that all players perceive as correlated with their share of profits. Another way of interpreting "fairness" is that players who invest more are paid more. In this sense we use the renowned Shapley Value function as a formal and proven solution concept that provides with a unique allocation of the coalition surplus such that none player would reject it because of taking it as unfair, thus increasing its viability. Its formality derives from a precise definition, provided its compliance with a given set of properties. From an economical perspective, our research question is: What constitutes a viable heuristic approach to sustainably achieve the benefits of JRP from a coalition determined by the Shapley value function under realistic settings?

In order to respond this question, a collaborative logistic schema is proposed (Figure 3-1). Its application is originally devised for cargo importers that do not compete in the same markets, restrained by storage capacity in their facilities as well as by container or transportation load size. A first issue consists of the coordination of replenishments between different importers to take advantage of the economies of scale derived from the JRP model. We assume importers are willing to participate in a joint replenishment initiative with other importers (collaborating players) that will improve their individual gains. The basic schema of operation is denoted in *Figure 1*. It starts with deliveries from different vendors consolidated by a 3PL to converge in a unified cargo flow towards collaborating importers. Considering the JRP under a cyclic policy, each importer needs to restock an amount of Q_i for the ith family of items with a frequency $T * k_i$, where T is a reference replenishment period and k_i is an integer. Without loss of generality, an item family is comprised by a set of related items or a single item.

Suppliers must ship freight to a merging point where a 3PL consolidates and unitize cargo. Assuming FOB (free on board) or FCA (free carrier) trading terms, transport costs up to the merging point are borne by vendors.

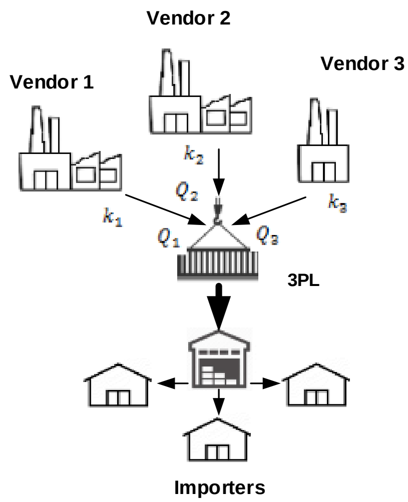


Figure 3-1: Proposed operation schema

Then the cargo is sent by sea to a destination port near the importers' facilities. Once there, importers share storage facilities and its costs. The scope of the proposed schema ends up with the breakdown of the cargo flow back to separate family items.

3.3 Literature review and the extended model

Khouja and Goyal (2008) indicated that JRP has already passed the saturation point and the time has come when current research should be focused on developing applicable models of the JRP for real life inventory problems. Although the classical JRP relies on unrealistic assumptions, there are works that reevaluate some of the classical assumptions. I.e., some authors acknowledge that inventory management in real life situations are limited by the capacity of some logistic resources (S. Goyal, 1975). In this sense, Hoque (2006) asserts that three of the more common and critical constraints in inventory systems are transport capacity, storage capacity and budget. More recent works show that there is a tendency to develop models considering multiple practical assumptions; e.g., Ongkunaruk, Wahab, and Chen (2016) reported a model simultaneously considering capacity constraints and the existence of defective items. Kiesmüller (2010) considers the capacitated JRP with stochastic demand rate in an environment where transportation costs are dominant and full truckloads are required. Paul, Wahab, and Ongkunaruk (2014) consider suppliers offering quantity discounts and the existence of imperfect items. Taleizadeh, Samimi, and Mohammadi (2015) presented a version of the classic model considering temporary discounts and full backordering.

Although the demand is a stochastic variable by nature, the stochastic version of the joint replenishment problem (SJRP) has not been extensively studied as the deterministic one. Two main types of policies have been proposed for solving the SJRP: periodic replenishment policy and can-order policy (Johansen & Melchiors, 2003). The first one was developed by Atkins & Iyogun (1988) for Poisson demands. It consists of stocking up the inventory to a quantity M_i each review interval T_i. On the other hand, in a can-order policy a stock up is made when an item has reached the must-order m_i level in a quantity enough to reach the level M_i. All items that have the level can-order c_i when an order is triggered can stock up to $M_{i.}$ Pantumsinchai (1992) developed a comparison between 3 methods: can-order policy, a modified version of the periodic review (MP) (Atkins & Iyogun, 1988) and a policy proposed by Renbeg and Planche (1967) denominated: A, M. The last one consists in monitoring the aggregate inventory and when a level A is reached it generates an order up to M for all items. In conclusion, A, M and MP policy have a comparable performance. However, A, M has a better performance than can-order policy in problems with high ordering cost, small number of products and low shortage costs. Can-order policy only has a better performance in problems with small ordering costs.

To jointly consider all available JRP variations implies complex modeling, a brave but perhaps not a viable effort. In order to our model to contemplate recurrent practical assumptions while within a feasible scope, it is assumed a normal demand with fixed lead times, multiple buyers, warehouse and transportation capacity constraints, a cyclic replenishment policy and periodic review policy. In this research, demand is considered stationary and forecast errors are normally distributed. The main support for the normality assumption in demand is found on the works of Eynan & Kropp (1998); Peterson & Silver (1979); Silver et al. (1998), as enumerated: (1) empirically, normal distribution fits better than other distributions to the demand, (2) when adding the forecast errors of many periods, a normal distribution would be expected due to the central limit theorem and (3) the normal distribution allows analytically tractable results.

In addition, as a distinctive assumption, the S-CJRP is a JRP stochastic version that incorporates the Shapley Value function to allocate the collaboration cost incurred by each colluding company (player). The main assumptions considered in our model are listed below:

1. *The replenishment lead time is fixed and the difference between the vendor lead times is insignificant.*
2. *Multiple buyer, products and vendors are considered.*
3. *Demand rate is stochastic (normally distributed).*
4. *Limited warehouse capacity.*
5. *Limited and homogenous transport capacity.*
6. *The cargo is compatible and non-perishable.*
7. *The players agree to use the Shapley Value as an allocation method.*
8. *Shortage is not allowed.*
9. *Quantity discounts are not available.*

It should be noted that the seventh on the previous list is not part of the JRP's usual assumptions, since it is introduced in our particular integrated version with *Game Theory* methods used to allocate the benefits gained from the collaboration. The Shapley Value is one of the more important concepts of fairness in the literature (Elomri, Ghaffari, Jemai, & Dallery, 2013). A fair allocation implies that each player is satisfied with his allocated savings according to his contribution and/or to the other player's savings. The section 4.3 extends the discussion along these lines.

Table 3-1 differentiates the S-CJRP from other JRP recent extensions. Within the comparable works stands out Kiesmüller (2010) who reported a constrained and stochastic version of the JRP and continuous review policy. The author models the demand process of each item as a compound renewal process, which means that demand sizes as well as interarrival times of demand are Erlang distributed. A similar continuous versión is provided by Mustafa et al. (2010) but considering a Poisson distribuited demand. In addition the work considers transportation capacity constraints and stockout costs. In contrast with the former, S-CJRP uses a periodic review, which reportedly outperforms the continuous review for high ordering costs (Pantumsinchai 1992). Qu, Wang, and Liu (2015) exhibited a stochastic demand version with periodic review, cyclic replenishment policy and stock out costs, but disregards capacity constraints. The demand rate fluctuations are absorbed by means of a security stock modeled using a Normal distribution. A comparable work to Qu et al. (2015) was presented by Braglia, et al. (2016) but adittionaly allowing for controllable lead times and backordering mixtures. S-CJRP makes a difference with respect to Qu et al. (2015) and Braglia, et al. (2016), explicitly considering both transport and warehouse limitations. In another hand, within the reported works considering multiple buyers, all of them features deterministic demand and neglects practical capacity constraints, as opposed to S-CJRP. No other work reviewed intends to allocate the cost and savings incurred by each colluding company (player), as in S-CJRP.

Next, the model notation is defined:

TC	*Total annual cost (ordering, holding and transportation cost)*
M_s	*Set of family items* $M_s = 1,2,3, \dots, M$
N_s	*Set of players* $N_s = 1,2,3, \dots, N$
n	*Number of item families,* NxM
I	*Set of family items/players pair* $I = \bigcup_{y \in M_s, z \in N_s} (y,z) = \{(1,1),(1,2), \dots, (1,N), \dots, (2,1),(2,2) \dots (2,N), \dots, (M,N)\}$
D_i	*Annual demand rate for the item* $i, i \in I$
L	*Vendor lead time*
σ_i	*Standard deviation for the item* $i, i \in I$
$Z_\propto$	*Security level*
S	*Major ordering cost*
s_i	*Minor ordering cost for the item* $i, i \in I$
T	*Time between two consecutive replenishments*
h_i	*Holding cost for the item family* $i, i \in I$
k_i	*A positive integer multiple of* T *for the item* $i, i \in I$
A	*Cost of a full transport/container unit*
W	*Maximum capacity of a transport unit*
w_i	*Weight/volume per unit of item* $i, i \in I$
H	*Maximum storage capacity available*

Table 3-1: Comparison among some recent work

Reference	Demand		Lead Time		Review Policy		Multi Buyer	Cyclic Replenishment Policy	Stockout Costs	Constraints	Special Features
	Stoch.	**Determ.**	**Fixed**	**Controllable**	**Periodic**	**Continuos**					
(Kiesmüller, 2010)	X		X			X				X	Service level constraint, full truckload policy
(Yu-Chung, et al., 2012)		X	X		X						Credit periods and freight weight discounts
(Amaya, et al. , 2013)		X	X		X			X		X	
(Y.-C. Tsao & Teng, 2013)		X	X		X			X		X	Trade credits
(Wang, et al., 2013)		X	X		X		X	X			Fuzzy costs deliveries schedule
(Paul, et al., 2014)		X	X		X						Imperfect ítems, price discounts
(Narayanan & Robinson, 2010)		X	X								Rolling horizon, dynamic lot-size
(Mustafa, et al., 2010)	X		X			X			X	X	Constant size orders
(Qu et al., 2015)	X		X		X			X	X		Integration with with location decision
(Yao & Huang, 2017)		X	X		x			x		x	Warehousing cost
(Cheung, et al., 2016)		X	X								Dynamic lot-size
(Brahimi, etal., 2015)		X	X							X	Two level inventory
(Bienkowski et al., 2015)		X	X								Demand with deadline
(Braglia, et al., 2016)	X			X	X			X	X		Backorders-lost sales mixtures
(C. K. Chan, et al., 2003)		X	X		X		X	X			
(Li, 2004)		X	X		X		X	X			
(Hoque, 2006)		X	X		X			X		X	
(Porras & Dekker, 2006)		X	X		X			X			Minimum lot-size
(Moon & Cha, 2006)		X	X		X			X		X	
(Ai, et al., 2017)		X	X		X			X			Full backlogging, non-instantaneous deteriorating items
(Ongkunaruk, et al., 2016)		X	X		X			X		X	Defective items
(Yousefi, Aryanezhad, Sadjadi, & Shahin, 2012)		X	X		X				X		Bi-objetive
(Hoen, Tan, Fransoo, & Van Houtum, 2014)		X	X		X			X		X	Carbon emission constraint
The S-CJRP	***X***		***X***		***X***		***X***	***X***		***X***	***Integrated with Shapley Value.***

Source: extended from Braglia, Castellano, and Gallo (2016)

The major ordering costs are those that do not depend on the number of items included in an order. These costs tend to be fixed given the insensitivity to the different nature of the items as unified cargo from the ordering process, corresponding to: container fees, those due to the processing of documents, preparing and receiving orders, and materials management. On the other hand, minor costs surge over the treatment variety introduced by different family items included in an order. These are related with the costs of manipulation, processing and additional efforts due to the individual items. The model also includes an extra charge in minor costs per item for additional coordination efforts of aggregated cargo, which are not necessary in separate item transactions.

The reported strategies for solving the JRP are divided in two (Khouja & Goyal, 2008): a direct grouping strategy (DGS) and the indirect grouping strategy (IGS). For the first one, items are assigned into a predetermined number of sets and the items within each set are jointly replenished with the same cycle. The second one (IGS) consists in determining a fixed regular time interval per item in which items are replenished in a quantity large enough until the next replenishment. The time intervals per item are given by an integer multiple of a common time interval and items with the same integer multiple are jointly replenished, so that groups are indirectly formed. Under IGS is verified that a jointly replenish with all items could not be optimal, since could exist different groupings rendering a better solution. Eijs, Heuts, and Kleijnen (1992) assert that IGS outperforms DGS for higher major ordering costs because many items can be jointly replenished when using an IGS. In this research, the JRP is solved using IGS strategy. The proposed objective function is composed by three components. The first in (1) refers to the annual ordering cost, where for each period (T) a major ordering cost (S) is incurred plus an aggregated minor ordering cost s_i from the *i*-th item each k_i per T periods, as follows:

$$= \frac{S}{T} + \sum_{i \in I} \frac{s_i}{k_i T} = \left(S + \sum_{i \in I} \frac{s_i}{k_i}\right) / T \tag{3-1}$$

The second represents the holding cost, defined as the cost of keeping the average of units stocked over the time horizon, such as follows:

$$= \sum_{i \in I} \left(\frac{D_i k_i h_i}{2}\right) T = \frac{T}{2} \sum_{i \in I} D_i k_i h_i \tag{3-2}$$

The third refers to the annual holding cost including both cycle and security stock:

$$= \sum_{i \in I} Z_{\infty} \sigma_i h_i (\sqrt{L + T k_i}) \tag{3-3}$$

The last refers to the total transportation cost, which is calculated as the sum of the cost by transport the total volume $w_i D_i k_i T A$ of item *i*, in transport units with capacity W a number of times $\frac{1}{k_i T}$ over the time horizon, that is:

$$= \sum_{i \in I} \left(\frac{w_i D_i k_i T A}{W k_i T} \right) = \sum_{i \in I} \left(\frac{w_i D_i A}{W} \right) \tag{3-4}$$

In many inventory models, transportation cost is included as a fixed value within the ordering cost. It is generally assumed that the transportation cost does not depend on the size of the shipment (Ertogral, Darwish, & Ben-Daya, 2007). However, in recent researches, transportation cost is considered as an independent element of the ordering cost (Bravo & Vidal, 2013). Kang et al. (2016) consider transportation not only as a separate cost element, but also allow for multiple types of transportation. Our research contemplates a single type of transportation with an associated fixed cost and standardized capacity limit.

The expression in (4) indicates that the transportation cost is independent of the basic cycle time. Thus, from the aggregation of (1), (2), (3) and (4) we obtain in (5) the cost objective function of the proposed model. The extension for the JRP model is introduced as follows:

$\boldsymbol{Minimize}$: $TC(T, k_1, k_2, \dots, k_n)$

$$TC = \left(S + \sum_{i \in I} \frac{s_i}{k_i} \right) / T + \frac{T}{2} \sum_{i \in I} D_i k_i h_i + \sum_{i \in I} Z_\infty \sigma_i h_i (\sqrt{L + T k_i}) + \sum_{i \in I} \left(\frac{w_i D_i A}{W} \right) \tag{3-5}$$

$Subjet\ to$:

$$\sum_{i \in I} D_i T k_i w_i + \sum_{i \in I} Z_\infty \sigma_i w_i (\sqrt{L + T k_i}) \leq H \tag{3-6}$$

$$T > 0\ ;\ k_i \in \mathbb{N}\ \forall\ i \in I$$

Constraints (3-6) are concerned with the warehouse limited capacity. It should be noted that the objective function in (3-5) depends on the variables T and k_i.

3.4 Heuristic Approach

In this section it is described the proposed approach to solve the S-CJRP. First, it starts by finding all the possible coalitions (combinations of players) over the set of players N. Then, for each one of the coalitions we need to calculate its expected value $V\,(S_j)$, which represents the average operational cost of such coalition. Each $V\,(S_j)$, also called characteristic function, is obtained by solving a sub-problem with fixed parameters $D_i, h_i, W, w_i, S, s_i, A, \sigma_i, Z_\infty, L$ and H. That given sub-problem can be expressed as an instance of the capacitated JRP, which is solved using Genetic Algorithms (GAs) as described in Section 4.2. Finally, we calculate the Shapley Value taking iterative inputs from all possible coalition costs determined by the GAs and use it as an allocation technique, as more extensively shown in Section 3.4.3. A general algorithm for this procedure is shown:

Step 1: *Determine all possible coalitions* S_j *over* N

Step 2: $For\ j = 1{:}\ 2^{|N|} - 1$

Calculate $V\ (S_j)$ by solving the sub-problem (S-CJRP)

with: $D_i, h_i, W, w_i, S, s_i, A, \sigma_i, Z_\infty, L, H$, where $i = 1,2,3, \dots, |S_j|$

Step 3: Calculate the Shapley Value using all $V(S_j)$

The heuristic procedure integrates GAs and the Shapley's function, as shown in Figure 3-2. The proposed evolutionary process required to assess the Shapley value must be executed $2^{|N|} - 1$ times, one per each characteristic function. In our case, such function was shown in (3-5) and depends upon the players' parameters. The Shapley Value is a #P-Complete problem (Deng & Papadimitriou, 1994). The number of iterations $(2^{|N|} - 1)$ is exponential, so the required computations become impractical for particularly complex characteristic functions. We use GAs to reduce the computational complexity of each JRP iteration, decreasing in this way the overall burden of the problem. The former illustrates the unique and seamless interaction of the S-CJRP components, given that only by means of GAs the numerous JRP instances can be computed to assess the Shapley function. On the other hand, although our GA (Step 2) is capable to solve large JRP problems, it solves the Shapley's function by exact methods. This implies that for problems delivering more than 30 items, calculations on a conventional computer could be prohibitive. Luckily, this is a minor issue since in the model one item could represent a family of items composed by tens or hundreds of aggregated items that can be jointly replenished. The items in a family oftentimes share similar demand patterns, uses and physical features, which is why they can be unified in the model.

To illustrate, the example denoted in the Figure 3-2 shows an instance of two players, where only three coalitions can be obtained: $\{J_1\}$, $\{J_2\}$ and $\{J_{1,} J_2\}$ (Step 1). Hence, it is necessary to calculate three characteristic functions $V(J_1), V(J_2), V(J_1 J_2)$ (Step 2) to obtain a cost allocation vector after calculating the Shapley Value (Step 3), where $\varphi_1$and φ_2 indicate the individual expected cost assignment of player 1 and player 2 respectively, and overall individual contribution (i.e., cost saved from non-colluding situation) to the joint replenishment process cost. Final values for the parameters T and k_i are extracted from the coalition composed by all players.

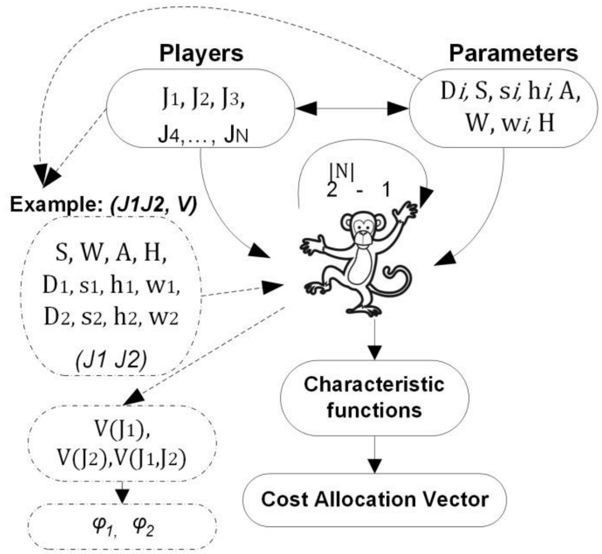


Figure 3-2: Summary of the JRP-Shapley Value integration process proposed

In the remaining of this section, we will first address the motivation of the use of GAs in solving the JRP, to later get back at the specifics of Steps 2 and 3 of the heuristic approach, focusing first on the use and calibration of GAs to then describe the benefit allocation by means of collaborative games.

3.4.1 Why GAs?

Arkin, Joneja, and Roundy (1989) proved that even the simplest JRP deterministic version is an NP-hard problem, exact optimization may be computationally prohibited. In the literature, some non-prohibitive computational heuristics algorithms have been proposed for solving the problem in a reasonable time (Nilsson and Silver 2007; S. Goyal and A 1979; Kaspi and Rosenblatt 1985; Lee and Yao 2003; Silver 1976; Kaspi and Rosenblatt 1983, 1991). Among the available methods, the GAs are particularly convenient by the following reasons:

I. GAs offer proficient solutions to the problem. Khouja, Michalewicz, and Satoskar (2000) reported GAs as an efficient heuristic to solve the JRP. The RAND algorithm achieved the optimal solution for about 83% of the problems in a sample of 1600 randomly generated ($with\ n = 10,20,30,50$). On the other hand, GAs attained the same total cost as RAND in 761 of the problems (63%), performed better in 6 problems and underperformed the RAND for 433 problems. Of those, the maximum percentage savings in total cost provided by RAND was 0.078% ($7.8 per $10.000) and the average percentage savings was 0.010% ($1 per $10.000). For the six problems in which the GAs outperformed the RAND, the average improvement was 0.012%.

II. GAs are easy to implement, close to 200 code lines. It converged to a good solution very fast for $n = 10,20,30,50$. No more than 50 generations and population of 100 chromosomes are necessary (Khouja et al., 2000a; Moon & Cha, 2006).

III. They constitute a very good alternative for solving the constrained JRP, which is the case of this work.Moon and Cha (2006) solved a constrained JRP using an extended version of RAND, called C-RAND. They compared its performance with GAs $(n = 10,20,30,50)$. In conclusion, GAs obtained very good solutions in short computational time. In average C-RAND outperforms GAs in 0.0294%, which represents a very low deviation from the optimum. GAs are especially meaningful by their extension ability when considering backorders, stochastic replenishment intervals or market situations as quantity discounts. In general, GAs are an effective alternative to JRP extensions where the involved optimization problem is prohibitive using exact methods, as in the case of integer-nonlinear problems (Taleizadeh et al. 2010).

IV. The complexity of the GA's is proportional to the value of its parameters. Designing a convenient chromosome allows reducing the computational time without decreasing the quality of our solutions. See the algorithm complexity proof in the Appendix A.

3.4.2 JRP solution by genetic algorithms technique

GAs are inspired in the Darwinian theory of survival and the evolutionary behavior of populations. This technique is part of the known Swarm Intelligence (SI). In this section we will initially illustrate the application of a GA in solving the JRP, as proposed in Step 2 of Section 4. Such procedure is composed of three stages: (I) Initial population and chromosome representation, (II) evaluating the objective and fitness function, and (III) creating new populations using reproduction, crossover and mutation operators. Finally, an additional subsection deals with the calibration of the GA in order to determine the parameters used in the present study.

3.4.2.1 Initial population and chromosome representations

An important consideration before generating the algorithm is designing the representation of a solution (chromosome formed by several genes). It is desirable that solutions are always feasible; however, this is not always possible. In this work, the technique proposed by Moon and Cha (2006) was used to ensure feasibility. The chromosome is a vector of *n* positions, each one of them is represented by a random number $\sim[0,1]$. Each position (gene) represents an item i and the random number in the ith position can be decoded to an integer number k_i, as shown in (3-7).

$$k_i = k_i^{LB} + \lfloor (k_i^{UB} - k_i^{LB} + 1) * Gene(i) \rfloor \qquad (3\text{-}7)$$

For calculating the k_i lower bound (k_i^{LB}) and upper bound (k_i^{UB}), the procedure proposed by Khouja et al. (2010) was used. k_i^{LB} should be at least 1, satisfying the condition that, in the worst case, an item should be replenished in every order. For the lower bound, Khouja et al. (2010) used the expression: $k_i^{UB} = \lceil T_i^{IN}/T_{min} \rceil$, where T_i^{IN} is the individual optimum cycle time for each item using the EOQ model ($\sqrt{S(S + s_i/D_i h_i}$) and T_{min} is the lowest cycle time between all items. However, Khouja solved the problem for a deterministic demand situation, whereas our proposed model considers stochastic demand. So, T_i^{IN} and T_{min} was obtained using the heuristic developed by Eynan & Kropp (1998), as follows:

$$T_i^{IN} = \sqrt{2(S+s_i)\Big/h_i\left(D_i + \frac{Z_\infty \sigma_i}{\sqrt{L+T_0}}\right)} \tag{3-8}$$

Where

$$T_0 = \sqrt{2(S+s_i)/h_i D_i} \tag{3-9}$$

On the other hand, T_{min} can be calculated as:

$$T_{min} = \min \sqrt{2s_i/h_i\left(D_i + \frac{Z_\infty \sigma_i}{\sqrt{L+T_0}}\right)} \tag{3-10}$$

Where

$$T_0 = \sqrt{2s_i/h_i D_i} \tag{3-11}$$

This approach has some benefits:

I. The chromosome needs just n genes to represent a set of k_i integers $(k_1, k_2, \dots, k_n)$.
II. The chromosome can be easily decoded to a feasible solution.
III. A verification procedure is not necessary because feasibility of solutions is not influenced by any crossover or mutation.

3.4.2.2 Evaluating the objective by fitness function

In each generation the individuals are characterized by a fitness function which evaluates the quality of the solution. Since the problem has a single objective, the fitness value can be computed directly from the objective function in (5).

$$Fitness = \frac{1}{TC(T, k_1, k_2, \dots, k_n)} \tag{3-12}$$

To evaluate the objective function (3-5), one set of $k_i's$, and a basic cycle time T are necessary. The optimal value of T could be calculated by taking the first derivative with respect to T from the objective function and equating it to zero. However, the third term of the expression (3-13) maintains the variable T implicit and inside a radical. So, equating a single value for T is not possible.

$$\frac{\partial TC(T)}{\partial T} = -\left(S + \sum_{i=1}^{n} s_i/k_i\right)/T^2 + \frac{1}{2}\sum_{i=1}^{n} D_i h_i k_i + \sum_{i=1}^{n} \frac{Z_\infty \sigma_i h_i k_i}{2\sqrt{L + Tk_i}} = 0 \tag{3-13}$$

To solve this problem, the optimal value of T proposed by Eynan & Kropp (1998) was used. They demonstrated that an approximation to this value closer to 98% is provided by expression (3-14) for stochastic models of periodic review.

$$T_1 = \sqrt{2\left(S + \sum_{i=1}^{n} \frac{s_i}{k_i}\right) \Big/ \sum_{i=1}^{n} h_i k_i \left(D_i + \frac{Z_\infty \sigma_i}{\sqrt{L + T_0}}\right)} \tag{3-14}$$

Where

$$T_0 = \sqrt{2\left(S + \sum_{i=1}^{n} \frac{s_i}{k_i}\right) \Big/ \sum_{i=1}^{n} h_i k_i D_i} \tag{3-15}$$

For the constraint (3-6), the value of T cannot be solved easily. Therefore, this paper proposes a heuristic procedure to calculate it, as follow:

```
T2 finder(A, B)
        If (B − A) ≥ 0,01 then
            V ← A + (B−A)/2
            If β(V) ≤ H then
                T2 ← T2finfer (V, B)
            Else
                T2 ← T2finfer (A, V)
            End if
    Else
            If β(B) ≤ H then
                T2 ← B
                Else if β(A + (B−A)/2) ≤ H then
                T2 ← A + (B−A)/2
                Else
                T2 ← A
                End if
            End if
            Return T2
END
```

Where

$$\beta(T_2) = \sum_{i\in I} D_i\, T_2 k_i w_i + \sum_{i\in I} Z_\infty \sigma_i w_i (\sqrt{L + T_2 k_i}) \tag{3-16}$$

In order to reduce the solution space we use the following expression $T_{max2} = \frac{H}{\sum_{i \in I} D_i k_i w_i}$ as the first T_2 which correspond to the optimum T when does not exist security stock.

Then, $T = \min(T_1, T_2)$. Using this approach, if $T_1 \geq T_2$ means that the feasible $TC(T)$ adds a penalty derived by observing warehouse capacity constraints, that increases shipments per period thus incrementing the ordering cost. If erroneously, T_1 is selected instead of T_2 when $T_1 \geq T_2$ the capacity restriction will be violated, and the warehouse space will be insufficient to store the replenishment orders. A discussion over these lines can be found in Moon and Cha (2006); Khouja, Michalewicz, and Satoskar (2000). Finally, the total cost can be calculated solving our objective function (3-5) with the values of: $T, k_1, k_2, k_3, \ldots, k_n$.

3.4.2.3 Creating new populations, crossover and mutation

Once all individuals are evaluated by the fitness function, then they are arranged according to their quality (low cost). Good solutions have a larger probability to transfer their genes to the next generation under a random selection.

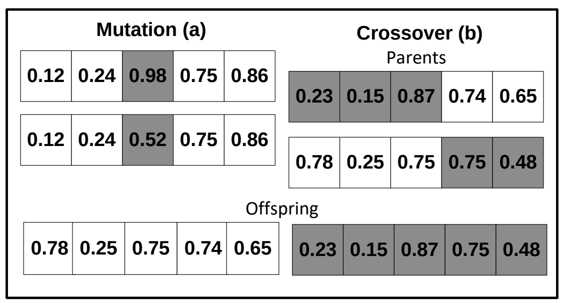


Figure 3-3: Mutation and crossover representation

Populations are formed by a percentage of best solutions (Pe) from the previous generation (elite) and a number (P_c) of offspring generated by the crossover of two parents that generate two sons (see Figure 3-3 (b)). The crossover quantity gene is randomly chosen.

Besides, a quantity (P_m) of solutions obtained from mutation process is included (see Figure 3-3(a)). Just a percent of a gene is replaced for another random number $\sim[0,1]$. A percentage (P_n) of new individuals are generated. The regular procedure of GA does not guarantee that the best individuals (elite population) found so far remain in the following generations. In this implementation, an elitist approach was applied in order to improve convergence, guaranteeing the permanence of the elite solutions and probably their descendants. It should be noted that the crossover and mutations are performed without decoding the chromosome. A representation of the basic procedure is presented in the Figure 3-4.

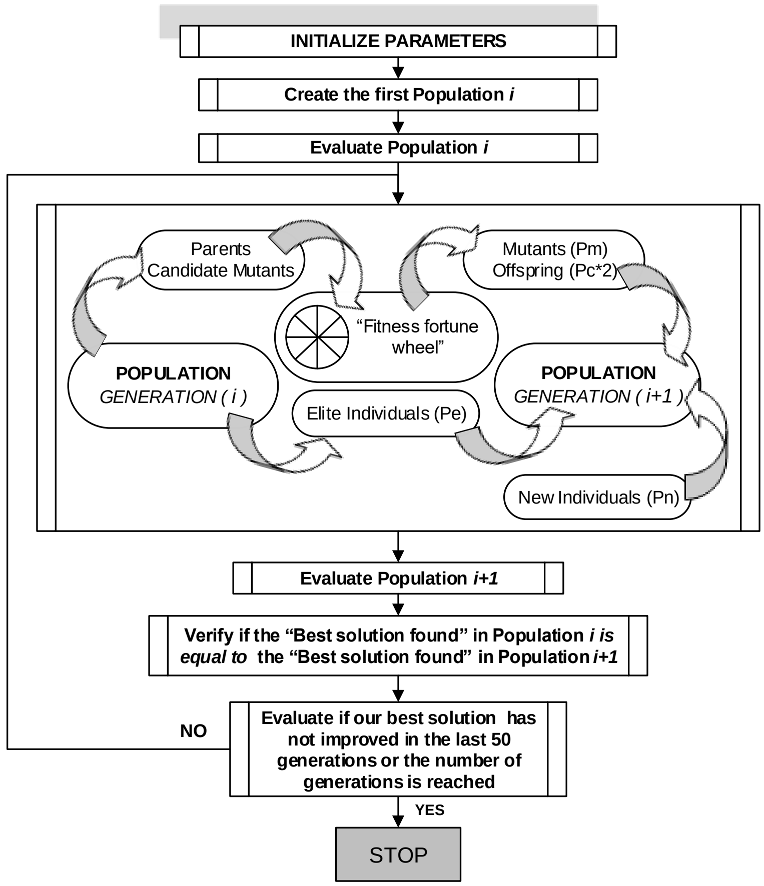


Figure 3-4: General framework of GAs in the JRP

3.4.2.4 Sensitivity Analysis

Calibrating GAs may constitute a large combinatorial problem, depending on the sensitivity of its parameters. For this case are considered four parameters: probability of crossover (Pc), probability of mutation (Pm), population size (M) and elite size as a percentage of population size (Pe). The primary concern was to improve the computational time required to reach the best solutions of several known problems. Random data for 400 problems were generated starting from the following initial values: $Pc = 0.7, Pm = 0.2$. The stopping criterion was set on 10,000 generation and the best cost obtained was kept as a reference value. Then, each parameter was defined considering its sensitivity, beginning by Pm, which had a moderate impact on the number of generations required to reach the reference values after varying his magnitude and fixing the other parameters; so the decision was to set $Pm = 0.2$. The percentage of elite population had a moderate sensitivity too, as illustrated in the *Figure* 5*(a)* for $n = 20\ and\ 50$. This figure shows that less generations are required to converge at the reference value when the Pe is set in 5%, but a big leap is not observed. Yet, the probability of crossover Pc has a high sensitivity and big leaps are obtained when all parameter are fixed and Pc varies, as shown the Figure 3-5(b*).* There is a big leap between the values 0.4 and 0.6, so it was set at the latter.

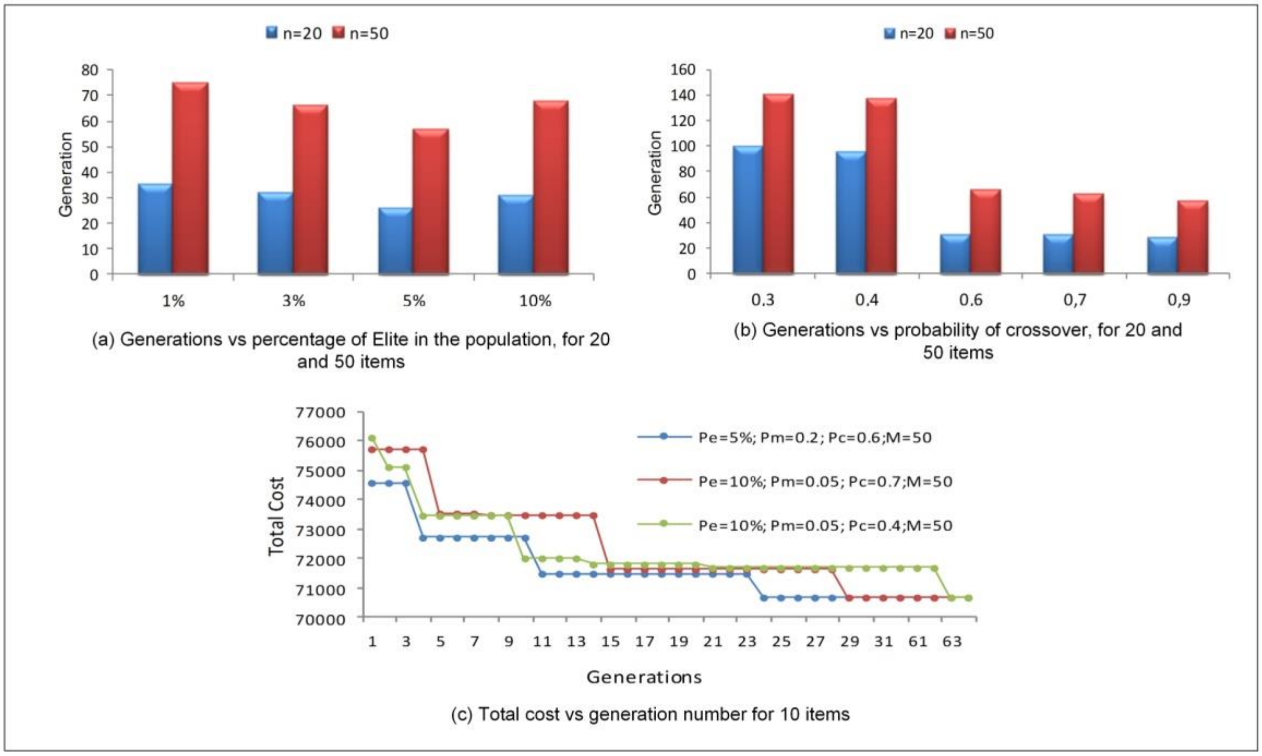


Figure 3-5: Percentage of elite individuals versus generation number, for a 20 and 50 family of items

The former procedure was applied to calibrate the population size M. By changing M are obtained dramatic changes in the number of generations needed to convergence. In brief, a value of $M = 50$ is adequate for $n = 10 \text{ and } 20$, but for $n = 30 \text{ and } 50$ is better to use $M = 100$. The Figure 3-5 (c*)* shows the results for a case where $n = 10$ and three sets of parameters were tested, in which the blue series considering $P_e = 5\%, P_m = 0.2, P_c = 0.6 \text{ and } M = 50$ reach earlier than the others the reference value. Such behavior is prevalent in most cases, for this reason the mentioned parameters were chosen as the final parameters but except for *M*, which is set to 100 when $n = 30 \; and \; 50$. The final termination condition is to stop if no improvement is made in 50 generations or 500 generations are reached.

3.4.3 Modeling collaboration in supply chain as a collaborative game

Game theory is a powerful tool for analyzing situations in which the decisions of multiple agents affect each agent's payoff. These agents called *players* are autonomous in their decision making to maximize their own benefits in a game, while other players seek the same simultaneously. A game is an iterative decision-making situation, where a possible profit is at stake. In such situation the players may decide to compete against each other, or to cooperate (forming a certain coalition), always seeking to maximize their gain. In supply chain management, Game Theory has been used as means to support the decision maker with both tactical and operational decisions, such as: capacity investment, planning production, locations problems, shipments schedules, inventory decisions among others. In the context of non-cooperative games, good surveys are provided by Cachon and Netessine (2004) and Leng and

Parlar (2005), presenting a great deal of supply chain settings, concepts and a variety of interactions between supply chain partners.

On the other hand, in the field of cooperative games the literature is less abundant. Within this field there exist different but related research lines, such as supply chain networks (Slikker & Nouweland, 2001), supply chain integration (Simatupang & Sridharan, 2005) and inventory management, also called as *inventory games*, among others. One useful survey for the latter is Fiestras-Janeiro et al. (2011), with a review of the applications of cooperative game theory in the management of centralized inventory systems.

Some of the central aspects in cooperative games are profit allocation and coalition stability. When players recognize promising gains from an eventual collaboration, some or all players could evaluate options such as joining together as a coalition and agreeing on a joint course of action. That situation generates two questions subsequently: (1) how will players in an alliance divide the gains obtained? And (2) what are the stable coalitions that emerge in a particular setting? One of the most complete reviews that address the aforementioned concerns is Nagarajan and Sošić (2008). The authors present and discuss several cooperative bargaining models to find allocations of the profit between supply chain partners and discuss the issue of coalition formation among players.

For the present research, the strategy of sharing replenishment costs is proposed as a cooperative game, thus coalition formation between players is allowed. Coalitions are possible because it is assumed in the interest of players to negotiate agreements through which they can reduce their costs (Myerson, 1991). The amount of papers related to situations where players share replenishment costs has grown significantly in the last years. The mayor interest has focused in supper-additive games, where the cost savings associated with a coalition increase with the number of players. In these games the grand coalition, which is formed by all the players in the game, is the best partition.

A central work in this area is Meca et al. (2004), featuring a joint replenishment inventory model based in the classic EOQ with a single item and supplier. This model considers only the holding and the mayor ordering cost, the independent ordering costs are disregarded. Under these assumptions is always optimal for all players to order jointly. In addition, the resulting inventory game has a non-empty core and they prove that proportional allocation rules belong to the core. The non-emptiness of the core implies that there exists at least one solution (allocation) that warrants stability, since the players do not have economic incentives to form a coalition different than the proposed. For a comprehensive theoretical framework on the concept of the core in game theory, we suggest Shapley (1967). More specifically in the context of inventory games, readers should review Dror and Hartman (2011). Subsequently, Moshe Dror and Hartman (2007) studied an extension of Meca et al. (2004) considering an independent ordering cost per item. Additionally, they provided the conditions to assure the non-emptiness of the core. Under this approach, items are always jointly replenished. For other extensions of this problem, consult Anily and Haviv (2007) and Zhang (2009).

Elomri et al. (2012) considered a model similar to Moshe Dror and Hartman (2007), but claiming that the grand coalition could not always be feasible for the players, since the game could not be supper-additive. In this case, the authors deal with two fundamental questions: (1) which coalitions are likely to be formed? And, (2) how will the players within these coalitions share their residuals? The authors assume that retailers can form coalitions while knowing that their savings will be allocated in a cost proportional basis. In this case, stability is referred in the sense of the coalition structure core: those structures are stable considering that no group of players can be better off when forming a sub-coalition.

This work considers an inventory model remarkably different to the models cited above. Firstly, we consider real-world constraints such as transport and warehouse finite capacity, and each player can have more than one item and different suppliers. A related work is in Fiestras-Janeiro et al. (2015) whom considered a model with warehouse constraint, a unique item and assumed holding costs to be zero. We deal with a mayor ordering cost, independent ordering cost and holding costs. Also, players share a common warehouse where all items are stored. A similar situation is addressed by Tijs, Meca, and López (2005), but player items are partially stored in a common warehouse. In addition, we consider that players can share transportation units such as Elomri et al. (2013). Another difference is the strategy solution approach: in the authors' knowledge, all reported models simultaneously replenish all items together, while it is considered that not all items are always jointly replenished; it is used the IGS strategy presented in *Section 3,* since such strategy reports lower cost solutions to the JRP. On the other hand, we use Shapley Value as an allocation method considering the sense of fairness that implies. Further discussion will be presented in the next section.

3.4.3.1 Allocating the benefits; Shapley Value

For a coalition $S \subseteq N$, where N is the set of all players, there is an expected value of the benefits obtained calculating the characteristic function $v(S)$ from item aggregation of players conforming S. The assignment φ_i of an entrance fee for each player to join a coalition must meet their own expectations and satisfies the following axioms:

I. *Symmetry:* The names of the players should not determine the allocation of payment; they must be completely interchangeable. If the marginal contribution of each is equal in all coalitions, then their payoff should be the same. This is:

$$\Delta_i (S) = \Delta_j(S) \; for \; all \; S \subseteq N \tag{3-17}$$

$$\varphi i(N,v) = \varphi_j (N,v)$$

$$where \; \Delta_i (S) = v(S \cup \{i\}) - v(s)$$

II. *Efficiency:* The sum of the values of the players is equal to the value of the grand coalition.

$$\sum_{i \in N} \varphi_i (N,v) = v(N) \tag{3-18}$$

III. *Dummy player:* If the contribution to every coalition of a player is cero, his payment is cero.

$$v(S \cup \{i\}) = v(S) \quad for\ all\ S \subseteq N, \text{then } \varphi_i(v) = 0 \tag{3-19}$$

IV. *Linearity:* This axiom states that the sum of payments of a player obtained from two games v and k on a set of players N is equal to the payment received for belonging to a set consisting of v and k. This is:

$$\varphi_i(v + k) = \varphi_i(v) + \varphi_i(k) \tag{3-20}$$

Considering these axioms, Shapley (1953) introduced a formula to calculate $\varphi_i(v)$, as follows:

$$\varphi_i(v) = \sum_{S \subseteq N-\{i\}} \frac{|S|!\,(|N| - |S| - 1)!}{|N|!} \left(v(S \cup \{i\}) - v(S)\right) \tag{3-21}$$

In this expression, all $|N|!$ orders for a player to integrate a coalition are equally likely, as the number of possible arrangements belonging to S is $|S|!$, meanwhile the number of possible arrangements of the players that make up a coalition after i is $(|N| - |S| - 1)!$. Then the probability that i integrates S coalition is $\frac{|S|!(|N|-|S|-1)!}{|N|!}$. The aim is to obtain the expected value of the payment; hence, each marginal contribution $(v(S \cup \{i\}) - v(S))$ is multiplied to its corresponding probability.

In addition to the Shapley rule, exists other classic allocations rules in the literature (Dror & Hartman, 2011). E.g. *Demand*, that performs allocating by the fraction of the total demand generated. *Individual* allocates by proportion of the individual costs. *Incremental* allocates by the marginal cost of each item. The *Nucleolus* (Schmeidler, 1969) that warrants a core whenever the core is not empty. *Lourderback* allocates in proportion to the difference between the individual cost and the marginal cost. Dror et al. (2008) developed thousands of samples to examine the behavior of these six rules and concluded that *Nucleolus* is the best allocation rule in terms of the number of times that the rule is in the core when the core is no empty. In a second place we found *Louderback*, followed by *Shapley* and *Incremental*. Finally, the *Demand* and *Individual* rule perform poorly. However, Shapley Value is recognized as the best rule that assigns according to the marginal contributions of the players. This rule is featured by one desirable property: fairness. As Elomri et al. (2013) warns, the concept of fairness could be confused with core stability, but it should be stated that fairness is not a sufficient condition for stability in the sense of the core. Elomri et al. (2013) provide examples and a deep discussion about how Shapley Value allocation can be non-stable in the sense of the core except for convex games, where Shapley Value is at the center of gravity of the core (Shapley 1971).

Still, this research does not pursue a core-stable allocation but rather a fair concept allocation. For this reason, we discarded the nucleolus rule and all other requesting core-stability. A fair allocation only implies that each player is satisfied with his allocated savings according to his contribution and/or to the other player's savings. For the sakes of S-CJRP, the Shapley Value's sense of fairness fits very well with the authors' interests; it was adopt the assumption that coalitions may be formed as long as players receive savings equitable to their investments and efforts. Similar use of the Shapley Value by its sense of fairness can be as well found in Krajewska et al. (2008) whom presented a horizontal cooperation case between freight carriers. Another reference is Bartholdi and Kemahlioğlu-Ziya (2005), where retailers share logistical costs in a pooling inventory situation.

In another hand, the proposed game could be or not supper-additive, meaning by this that the original (grand) coalition could not necessarily be the best partition. It was assumed that players share their cost information, which is public, and subsequently they run the proposed heuristic (*Section 4*). The players evaluate possible coalition formation considering their expected savings. If a given player does not consider his potential savings from colluding attractive enough, he would depart from such coalition, leaving the others free to run again our heuristic and analyze their expected savings. If a coalition is formed, it should operate at least during the planning horizon of the inventory. A similar situation using Shapley Value is addressed by Contreras et al. (2009) in the electrical industry. In such work, Shapley Value is not only used as an allocation method, but it also takes part of a heuristic that supports a coalition formation strategy in which the players, previously knowing their expected benefits, can decide if they would join or not the coalition. Furthermore, for the parameters used in the practical cases, about 95% of the coalitions were super-additive, so the grand coalition was the best option for all the gamers. This situation is to be expected considering that companies in geographic proximity, similar sizes, and under similar regulations should have similar cost parameters. Non-additive games occurred only in two cases, when the cost of a player exceeded more than three times the average cost of the other players in the coalition, or when their costs were substantially low, therefore collusion was not as attractive. In general, it is to be expected that under similar conditions between companies, collusion will be attractive.

Although our method does not warrant stability in the sense of the core, in the coming section we prove its pragmatic value since it systematically allows for potential economic benefits in more realistic inventory settings. Moreover, our approach is more concerned with the players' perception of fairness and a favorable investment return, which in our view is determinant for the permanency of a coalition.

3.5 Numerical examples

To validate the effectiveness of the S-CJRP approach, 900 problems with randomly generated parameters were produced. The problems were divided into groups of 300, each one with a fixed number of players. Amounts of 3, 4 and 5 players were considered to test whether or not their collaboration is fruitful. The number of players was set in a conservative way, because actual settings the cost of inventory management and replenishment coordination for larger coalitions could be substantial, and thus, unattainable or infrequent in practice. For each group, four sizes of item families $n = 10, 20,$ and 30 were considered, and 100 problems were developed for each n. The Demand (D_i) and unit volume (w_i) followed a uniform distribution between [1000, 100000], [0.05, 1], respectively. The holding cost (h_i) and standard deviation were uniformly distributed as a function of the mayor cost and demand $[0.01 * S, 0.15 * S]$, $[0.05 * D, 0.15 * D]$, respectively. Four different values for the mayor cost (S) were fixed (100, 200, 300 and 400) and the minor cost s_i was defined in terms of the mayor cost $(0.05 * S,\ 0.1 * S, 0.3 * S, 0.5 * S, 0.7 * S, S)$. Transport cost ($A$) and unit transport capacity (W) were fixed in $80 and 76 cubic meters, respectively. The volume per unit of item w_i was set to 1. The parameter Z_α was fixed in 1.64 ($\alpha = 0{,}05$) and the lead time assigned between 1 and 4 weeks. The Maximum storage capacity available (H), or warehouse capacity constraint for the coalition, was calculated as the sum of the minimum space required to store the individual cargo of the players when they acted independently. Such space is the expected cargo volume for each player when the JRP model orders multiple items and does not consider capacity constraints. The total cost generated individually by the players should be compared with the cost obtained by performing in the coalition. Some parameters need to be changed depending on the case. For the individual cases, it is necessary to generate a warehouse constraint (H_0) for each player, with the rest of parameters kept as formerly described. As for the coalition case, the holding and major ordering costs are calculated as the average of values observed in the individual cases before forming the coalition.

This work contrasts two methods for cargo consolidation, or coalition building: S-CJRP consolidation and LCL consolidation, referenced against the non-cooperative Individual base case. Both methods use the capacitated JRP and deliver a coalition that results in a unified cargo handled by a 3PL, hence obtaining equal global cost reduction as previously discussed. Yet, S-CJRP consolidation makes use of the Shapley Value to determine the average resulting savings due to each player involvement to then allocate the cost of participating in the coalition, or membership, accordingly; while Less-Than-Container (LCL) will proportionally charge (reduced) cost per player by transported cargo introduced. By using the LCL consolidation, players who contribute more significantly to the coalition cost reduction could achieve lower savings, with minor marginal advantage; while, those with a smaller contribution could receive higher savings, making the gainshare uneven and collaboration unattractive. On the other hand, the S-CJRP consolidation is fairer, given that their assignments are made considering the expected marginal share of the players in the cost reduction. Hence, coalitions derived from the S-CJRP consolidation are expected to be more likely to be formed.

The former is illustrated with an example using data from Table 2. Both cargo consolidation methods yield the same total cost of $ 5639, which can be obtained by adding the values of the LCL consolidation or the S-CJRP consolidation rows. Such figure is markedly reduced when compared to the total cost of $ 7534, the sum of all individual base cases. Table 3-2 results assume approximately equal cubic size (w_i) for all players' delivered items. Furthermore, the LCL consolidation row value depends on the cargo volume. For instance, Player 1 manages 8000 mts^3 of cargo per year meaning the 40% of the overall cargo. Thus, in LCL consolidation Player 1 is linearly responsible for 40% of the total cost ($ 2278.4). On the other hand, the S-CJRP consolidation method non-linearly allocates cost to Player 1 in the amount of $ 1870.8, while the Individual base case cost of $ 2332.4 always exceeds both. The difference between the base case and S-CJRP consolidation is 19.8% while with the LCL consolidation is 2.3%. With LCL consolidation, Player 1 receives little retribution and will probably give up the coalition. Conversely, if the S-CJRP consolidation is chosen his savings notably increase. The LCL method consistently appears less attractive for already big players, since their investment and collaborative effort does not add significant volume nor savings. On the other hand, S-CJRP would improve the benefit for Players 1 and 2, both significant contributors to the overall cost reduction, hence discarding LCL option even when Players 3, 4, 5 and 6 will prefer it. Then, such LCL coalition is deemed as not sustainable since Player 1 and 2 will leave the coalition, plus the resulting savings achieved by the rest will be smaller given that they alone add up to 75.7% of the total cargo.

Table 3-2: Summary results of the model application for 6 players

Player	**1**	**2**	**3**	**4**	**5**	**6**
Demand	8000	7000	3000	1000	600	200
Standard Dev (σ)	300	250	100	100	50	25
k_i	1	1	1	2	2	4
LCL consolidation ($)	2278.4	1993.6	854.4	284.8	170.9	57.0
S-CJRP consolidation ($)	1870.8	1666.1	891.9	579.6	398.5	232.1
Individual base case ($)	2332.4	2129.1	1286.8	840.8	599.8	346.0
Savings S-CJRP Consolidation	19.8%	21.7%	30.7%	31.1%	33.6%	32.9%
Savings LCL consolidation	2.3%	6.4%	33.6%	66.1%	71.5%	83.5%

Other Parameters: $Z_{\infty} = 1.64,\ h_i = 1, T = 0.1857\ \ w_i = 1, mts3$ for all players

Tables 3-3,3- 4 and 3-5 summarize the results obtained by applying the proposed model for 3, 4 and 5 players, respectively. The column section on the left of the tables, designated as 'Item families per player', corresponds to the number of items (or product) families assigned to each player. Two scenarios were considered for the assignation of products to the players: (S1) when the items quantity is evenly distributed among all companies and (S2) where some players deliver more items than others. I.e., from Table 3-3 and for a number of players of 3 with $n = 30$, for the second scenario (S2) player P3 has 24 items while P1 and P2 only 3 each. Then, the right column section denoted as 'Average Savings', lists savings that each company would have achieved by forming a coalition; this is, the difference in costs between forming the coalition and operating individually[1]. At the bottom, the tables offer a summary section: on the left side, in bold, there is the average and standard deviation of the savings for the two coalition building methods. On the right side, there are statistics per player and per coalition building method.

In the Table 3-3*,* for $n = 10$ and Scenario S1, the LCL consolidation method yields that players P1, P2 and P3 could achieve average savings of 39.9%, 36.4% and 21.2%, respectively; but player P2 and P3, being rational, would never admit this result in the light of the existence of an alternate arrangement provided by the S-CJRP consolidation method, in which larger savings of 38.4% and 27.2 respectively, could be achieved. Whenever at least one player is aware of a better option, she will decide to leave the proposed coalition to join another more favored. Hence, such coalition while attractive for some, it remains unfeasible because of the rejection from other member(s). From a more aggregate perspective: for $n = 30$, comparing the average savings (including scenarios S1 and S2) for both methods*,* the LCL

[1] It is assumed for the players a base scenario in which they do not consolidate cargo. Instead, they are involved in a less efficient direct shipping transport strategy for minor volumes of cargo for (almost) each separate family item (e.g., Imports)

consolidation average (30.2%) and S-CJRP (31.5%) appears to be comparable, but, LCL is not acceptable for P1 and P3, thus as coalition remains unfeasible. The same observation can be obtained from the overall average savings (in the general summary) of LCL consolidation (30.8%) and S-CJRP consolidation option (32.3%) since are comparable, although with S-CJRP slightly outperforming LCL. The same happens for the remaining Tables 3-5 and 3-5 in which the overall average savings values are again similar with slight dominance of the S-CJRP consolidation option. However, and most importantly, S-CJRP consolidation is *always* more attractive for *all* Players because of its already mentioned sense of fairness, hence always outperforming the LCL consolidation option.

Table 3-3: Summary results of the model application for 3 players

Number of item families (n)		Item families per player				Average Savings (%)							
						S-CJRP consolidation				*LCL consolidation*			
		P1	**P2**	**P3**		**P1**	**P2**	**P3**	*Avg*	**P1**	**P2**	**P3**	*Avg*
10	*S1*	3	3	4		35.1	38.4	27.2	*33*	39.9	36.4	21.2	*32.4*
	S2	1	1	8		33.5	44.6	18.9		38.6	46.7	11.5	
20	*S1*	6	7	7		41.6	32.6	31.4	*32.4*	46.1	31.4	10.6	*29.9*
	S2	2	2	16		41.2	38.2	9.3		41.9	45.3	4.1	
30	*S1*	10	10	10		29.8	30.4	33.4	*31.5*	19.7	35.5	30.7	*30.2*
	S2	3	3	24		44.2	43.8	7.4		46.3	45.6	3.2	
General Summary		*Avg*	*Std Dev*		*Avg*	*37.567*	*38*	*21.3*	*32.3*	*38.8*	*40.2*	*13.6*	*30.8*
S-CJRP cons.		***32.3***	***11.0***		*Min*	*29.8*	*30.4*	*7.4*	*31.5*	*19.7*	*31.4*	*3.2*	*29.9*
LCL cons.		***30.8***	***15.2***		*Max*	*44.2*	*44.6*	*33.4*	*33*	*46.3*	*46.7*	*30.7*	*32.4*

Table 3-4: Summary results of the model application for 4 players

Number of item families (n)		Item families per player					Average Savings (%)									
							S-CJRP consolidation					*LCL consolidation*				
		P1	P2	P3	P4		P1	P2	P3	P4	*Avg*	P1	P2	P3	P4	*Avg*
10	*S1*	2	2	3	3		29.1	30.1	27.3	25.4	*29*	34.6	34.5	18.6	15.2	*26*
	S2	1	1	4	4		43.1	38.2	17.2	21.2		51.2	33.8	8.5	11.2	
20	*S1*	5	5	5	5		25.5	23.5	28.3	29.6	*26.9*	17.6	30.2	36.6	20.4	*26.2*
	S2	2	2	8	8		37.2	33.5	17.3	20		38.2	39.1	12.3	15.2	
30	*S1*	7	7	8	8		33.9	34.7	24.7	24.4	*28.7*	45.1	29.7	19.5	21.2	*27.9*
	S2	5	5	10	10		35.1	38.2	17.9	20.7		38.8	42.3	9.9	16.3	
General Summary		*Avg*	*Std Dev*			*Avg*	*34*	*33*	*22.1*	*23.6*	*28.2*	*38*	*35*	*18*	*17*	*26.7*
S-CJRP cons.		*28.2*	*7.4*			*Min*	*25.5*	*23.5*	*17.2*	*20*	*26.9*	*17.6*	*30.2*	*8.5*	*11.2*	*26*

LCL cons.	*26.7*	*13*	*Max*	*43.1*	*38.2*	*28.3*	*29.6*	*29*	*51.2*	*42.3*	*36.6*	*20.4*	*27.9*

Table 3-5: Summary results of the model application for 5 players

Number of item families (n)		Item families per player						Average Savings (%)											
								S-CJRP consolidation						*LCL consolidation*					
		P1	P2	P3	P4	P5		P1	P2	P3	P4	P5	*Avg*	P1	P2	P3	P4	P5	*Avg*
10	*S1*	2	2	2	2	2		28.5	33.1	34	34.2	27.4	*31*	40.2	30.1	20.1	28.4	22.8	*26.5*
	S2	1	1	2	3	3		39.4	31.2	30.1	25.3	27.1		54.8	40.5	28.4	19.7	22.1	
20	*S1*	4	4	4	4	4		28.5	33.2	38.4	33.9	27.9	*32.2*	19.6	20.5	32.2	38.8	44.3	*30.3*
	S2	2	2	6	6	6		39.2	32.4	28.5	29.5	30.1		45.1	39.9	22.3	25.5	18.7	
30	*S1*	6	6	6	6	6		30.2	32.1	33.5	36.1	35.2	*32*	22.5	19.2	45.6	44.2	30.1	*30*
	S2	3	3	8	8	8		39.3	38.1	25.1	24.1	26.4		55.6	41.2	19.5	19.7	20.1	
General Summary		*Avg*	*Std Dev*				*Avg*	*34.2*	*33.4*	*31.6*	*30.5*	*29*	*31.7*	*39.6*	*31.9*	*28*	*29.4*	*26.4*	*28.9*
S-CJRP cons.		*31.7*	*4.5*				*Min*	*28.5*	*31.2*	*25.1*	*24.1*	*26.4*	*31*	*19.6*	*19.2*	*19.5*	*19.7*	*18.7*	*26.5*
LCL cons.		*31.1*	*11.5*				*Max*	*39.4*	*38.1*	*38.4*	*36.1*	*35.2*	*32.2*	*55.6*	*41.2*	*45.6*	*44.2*	*44.3*	*30*

From a financial perspective, the collaborative strategy attractiveness might be relative. For instance, in Table 3-3 for $n = 30$ and scenario $S2$, player $P3$ at best receives savings of 7.4% when involved in S-CJRP consolidation. Note that when acting independently, she already controlled 24 families of items, adding up to 30 when collaborating, hence not generating significant savings. So regardless of a fair allocation, for P3 it may not appear attractive enough to collaborate, thus preventing an eventual coalition with her participation. Nonetheless, this type of decisions depends on the actual context of companies and their markets.

In Table 3-5 (for 5 players), S-CJRP allocations are more equitable than in Tables 3-3 and 3-4, since additional players allow for a more even distribution of item families. In general, players with fewer items joining players with many items get substantially higher profits, as they benefit from low to high economies of scale. When players' inputs are comparable, they also get similar benefits. Back to Table 3-5, for $n = 30$ Scenario $S2$, the difference in items amounts between players $P1$ up to $P5$ is only 5 items, with S-CJRP yields of 39.3%, 38.1%, 25.1%, 24.1% and 26.4%, correspondingly. Comparing these results with the S-CJRP ones in previous Table 3-3, for *n* = 30 Scenario S2, only P3 notably underperforms on savings. Such results indicate that forming coalitions with similar Players, as in with comparable quantities of family items to deliver, renders evenhanded benefits. Furthermore, looking at the more evenly item distributed scenario S1, for $n = 10, 20 \text{ and } 30$. Table 3-5 shows that S-CJRP consolidation savings are always more uniform, thus fairer, than in Tables 4 and 5 with more varied item distributions, thus supporting that players with comparable investment also achieve comparable savings.

3.6 Chapter 3 conclusions and managerial insights

The JRP features as a highly applicable model in a variety of real-world settings, especially when having some its original assumptions revised to introduce new model constructs and crafted with complementary contributions from varied fields to handle and solve additional and more complex practical requirements. This chapter proposed an extended JRP solution approach, termed as Stochastic Collaborative Joint Replenishment Problem (S-CJRP). This approach offers new viable ways to reduce logistical costs for practitioners open to a coordinated stock replenishment in a collaborative effort with different non-competing buyers. the model considers stochastic demand, warehouse and transportation capacity constraints and varied items from multiple buyers. The average cost savings achieved by using this approach tried for 3, 4 and 5 players are respectively 32.3%. 28.2% and 31.7%. The robustness of the model was tested in a variety of both positive and negative collaboration scenarios for potentially partnering firms, in all cases consistently exhibiting benefits.

This chapter adds to the extant body of literature in two ways: first, our underlying JRP model is the first to concurrently deal with conditions such as normal demand, multiple items and vendors, non-zero lead times, finite warehouse and transport capacity. Such particular condition combination is frequently observed in practice and has been modeled considering a periodic and cyclic review approach solved by means of Genetic Algorithms, yielding rewarding economic results. As for the second, the S-CJRP is an eclectic heuristic approach incorporating inventory theory, optimization and cooperative games in a seamless interaction that supplements to deliver viable solutions intended to overcome usual collaboration barriers such as mistrust or suspicion. This is provided by the use of Shapley allocation, perceived as objective and fair. Collaborative practices have demonstrated to be useful when improving cost efficiency of inventory management processes, where savings could mean millions of dollars. S-CJRP increases the chances of making true the promised benefits of collaboration in the practice.

The numerical examples discussion compared results for two cargo consolidation methods: Stochastic Collaborative Joint Replenishment Problem (S-CJRP) consolidation and Less-Than-Container (LCL) consolidation. Both showed equal savings derived from the cost reductions of the capacitated JRP but with different savings allocation for the two methods. What is interesting here is that S-CJRP always delivers more reasonable options for knowledgeable players than LCL, since by the Shapley Value Function S-CJRP ensures that all players receive savings proportional to his contribution to the coalition. It was exposed that, despite the average savings by the LCL method might in some cases be greater for some players, it will not be the general case and a subset of the players will perceive it as harmful for their individual interest, leaving such coalition as not viable. Oppositely, coalitions derived from the S-CJRP Consolidation are more likely to be formed.

Nonetheless, S-CJRP features several limitations. The proposed approach is scalable, yet the present research has been conservative with respect to the size of coalitions. It remains as an issue to demonstrate that the greater cargo volume is, the greater savings could be achieved. Additional costs and more extensive coordination efforts demanded by larger coalitions, rests as well as a question to be solved.

Moreover, in this research it was assumed that an initial number of players (N) constitutes the coalition. Nonetheless a different coalition with less players, or subsets of the original, could be more fruitful, since some players may not contribute in effective way or may harm the total benefits obtained. Under S-CJRP, potential players of a coalition evaluate their expected savings after running our heuristic. If savings are attractive, then players are expected to form such coalition, at least during a whole replenishment cycle (i.e., $max[k_i T]$). If a given player departs from the coalition, the remaining players can always run again our heuristic. It is not within our scope to warrant stability in the sense of the core, by providing the optimal coalition out of an initial group of N players. This approach is more concerned both with the players' perception of fairness and a favorable investment return, which in our view is determinant for the permanency of a coalition. Thus, future works should aim for solving the problem of finding most efficient coalitions over a number of given players and provide insights about allocations in a core-stable way.

Regarding some managerial insights, it was shown that coalitions formed by players of equal size (of items) generate smooth benefit allocations; conversely, small players get greater benefits, which might introduce conflict with big players. Therefore, it is desirable to form coalitions between homogeneous players. On the other hand, the proposed logistical strategy could be useful to reduce the management cost of products that typically imply both large holding and ordering cost. In this sense, it is desirable a joint replenishment in order to exploit economics of scale such as exposed by Ai, Zhang, and Wang (2017), whom exhibited a JRP model useful to manage perishable items. A similar case occurs with items that suffer evaporation (Taleizadeh 2014). A matter to consider in real life applications is to bargain competitive prices with the 3PL company in charge to consolidate the cargo. Considering the extra cargo introduced by the coalitions, the expectation is to obtain better prices than the regularly applied. A critical insight is that the decisions of some players affect the results of all, since the lack of compliance on a proposed agreement, i.e., a missed schedule resulting in delivery fail, will increase the total cost. Practitioners and decision makers shall work in order to find mechanisms to guarantee coordination in the replenishments.

The present chapter introduced the S-CJRP model and its solution strategy, as well as exhaustive tests to validate its usefulness. In the next chapter, such tests will be supplemented but introducing a new element; Lead times will be considered stochastic. In addition, three additional issues will be discussed and expanded. First, knowledge of the mechanisms used by the S-CJRP model to exploit economies of scale will be discussed and expanded, and it is demonstrated that this is a viable alternative to finance the expansion of logistics resource capacity. Second, it will be discussed whether the coalition's coordination should insource or outsource, and finally, a strategy will be presented to include new players to previously formed coalitions.

CHAPTER 4. A Collaborative Logistical Cost-Reduction Approach for Non-Competitive Small- And Medium-Sized Enterprises: Exploring S-CJRP Coordination and Variability Aspects Through Discrete-Events Simulation

This chapter explores the Stochastic Collaborative Joint Replenishment problem (S-CJRP), a collaborative approach suitable for non-competitive small- and medium-sized enterprises (SME's), aimed to reduce logistical cost by means of a joint replenishment. S-CJRP is an extension of the classical joint replenishment problem (JRP), since it considers real-world stochastic demand, finite warehouse and transport capacities, and multiple buyers and vendors. In this chapter, the model presented in Chapter 3 (S-CJRP) is extended by integrating the S-CJRP heuristic procedure with discrete simulation techniques (DES), thus introducing stochasticity in additional components of the ordering process and more detailed settings covering collaboration mechanisms. It is posed as an overall contribution; an improved understanding of the model's usefulness and indispensable policies for practitioners when implementing it. As output, experimental results confirm potential savings by the use of the collaborative strategy (28.35%) even when are considered unexpected changes in lead times and ordering costs, as well as are provided several helpful insights when implementing the S-CJRP.

The specific contributions of this chapter are:

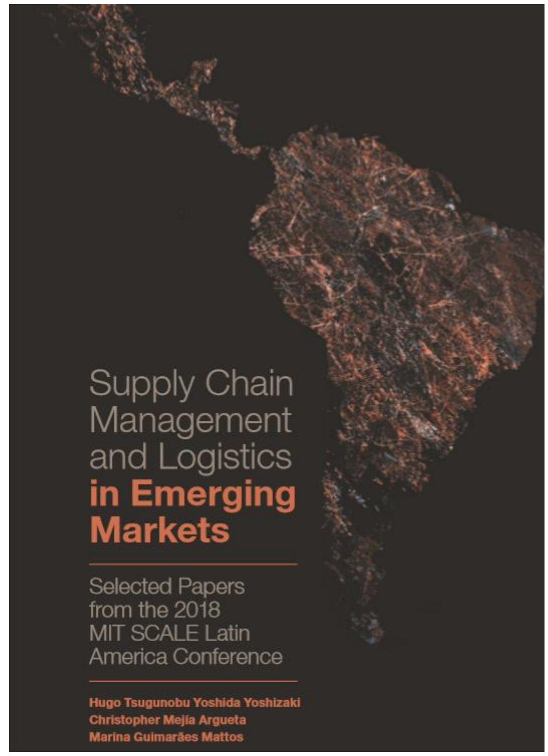
***** The improvement in the understanding about how to exploit the S-CJRP potentials and the formulation of policies regarding coalition member selection to increase benefits and facilitates surplus allocation through the analysis of experimental settings for a variety of players with different features. ***(Introduced in Chapter 3 but complemented with further tests)***

***** The improvement in the understanding of how the model can be a financially preferred alternative to access economies of scale from S-CJRP enabled cooperation than investment in individual capacity.

***** Insights and directions of why outsourced coordination seems to be the natural choice for S-CJRP coalitions, given the established high costs and risks of a discoordinated coalition operation that demands an expert coalition management.

***** Managerial insights about how to handle with the entry in a coalition of additional players, showing that generally requires not only additional expenditures but also a proposed prospect savings fee, which should be both charged to a newcomer as an entrance fee.

The current chapter is based on the next publications: Otero-Palencia, Carlos; Amaya-Mier, René; Montoya-Torres (2019); Otero-Palencia, Carlos Amaya-Mier, Motoya-Torres, & Jaller (2020)*, however, the main source is the first one, which was preliminary accepted by the editor and is under review:*



4.1 Introduction

This chapter proposes once again joint ordering as collaborative means for non-competing retailers with limited resources for reducing logistics costs. Recall, in general terms, the JRP deals with the problem of coordinating the replenishment of multiple items. However, it is based on the assumptions of deterministic demand and infinite capacity for transportation and warehousing. An extension of this problem, named the Stochastic Collaborative Joint Replenishment Problem (S-CJRP) was introduced by Otero-Palencia, Amaya-Mier, & Yie-Pinedo (2018) (introduced in Chapter 3), in which stochastic demand, limited warehouse and transport capacities and simultaneous interaction of multiple vendors and buyers are considered. These authors introduced a heuristic approach that solves the S-CJRP delivering viable collaborative inventory management cost reductions. Yet, this chapter seeks to explore an important subset of S-CJRP limitations and offer further analysis in the context of what it is considered one of its most promising fields of application: small- and medium-sized (SME's) inbound logistics with particularly high ordering costs (i.e., international trade supply chains).

Given an explorative purpose, it is proposed discrete-event simulation (DES) to extend the analysis of the effect of some S-CJRP deterministic parameters of interest, as well as to introduce and further analyze S-CJRP collaboration issues. Although the S-CJRP model is not modified, variations in the lead times are considered by means of a simulation model in recognition that the lead times are indeed stochastic variables in the practice. However, even with the incorporation of these variations, it is verified that the surplus significantly persists when it is used the collaborative proposed strategy. This chapter focuses on three supplementary issues to the S-CJRP version introduced in Chapter 3 by the work of Otero-Palencia, Amaya-Mier, & Yie-Pinedo (2018): (I) to improve the understanding of how the increase in scale through collaboration can leverage capacity expansion outperforming the individual investment; (II) should the coalition coordination be insourced or outsourced to a third party, since discoordinated operations introduces greater risks and added costs; and (III) how to manage the entry of new players into a previously established coalition.

The structure of the Chapter is as follows. Section 4.2 introduces the model motivation, the mathematical model, and assumptions. Section 4.3 details the proposed solution approach and explores the advantages of increasing transport and warehouse capacity by means of collaboration, contrasting cost reduction options for collaborative vs. individual methods. Section 4.4 addresses the S-CJRP's supplementary issues. First, it explains how the collaborative model reduces the cost. Second, it discusses whether the coordination role of the proposed solution should be better insourced or outsourced. Finally, it discusses the issue of new player's entry management to a coalition. Lastly, Section 4.5 summarizes policies and results, highlighting findings and drawing some opportunities for future research.

4.2 Motivation

This section introduces and discusses the need for further analysis the S-CJRP in its original version to deal with the stochastic issues previously described. Section 4.2.1 describes the model and its applicability in real settings, while Section 1.2 details the model features and assumptions. In the same section, it confronts some model inaccuracies against observed actual settings, in order to identify S-CJRP current limitations in the context of implementation. Finally, Section 4.2.3 presents the mathematical model and notations.

4.2.1 The S-CJRP in practice

Recall the S-CJRP proposes a collaborative solution which takes advantage from the coordinated replenishment of multiple items in order to apportion fixed ordering costs among partnering buyers. In the context of this chapter, coordinated or joint replenishment refers to the process where a set of partnering buyers agree to comply with a shared replenishment policy that reduces their individual logistics costs due to an increased scale of operation from the collaboration. Such buyer set shares reasonable proximity among its members, in order to receive a consolidated cargo; similarly, its set of corresponding suppliers should be co-located within reasonable distance to allow for shipments merging.

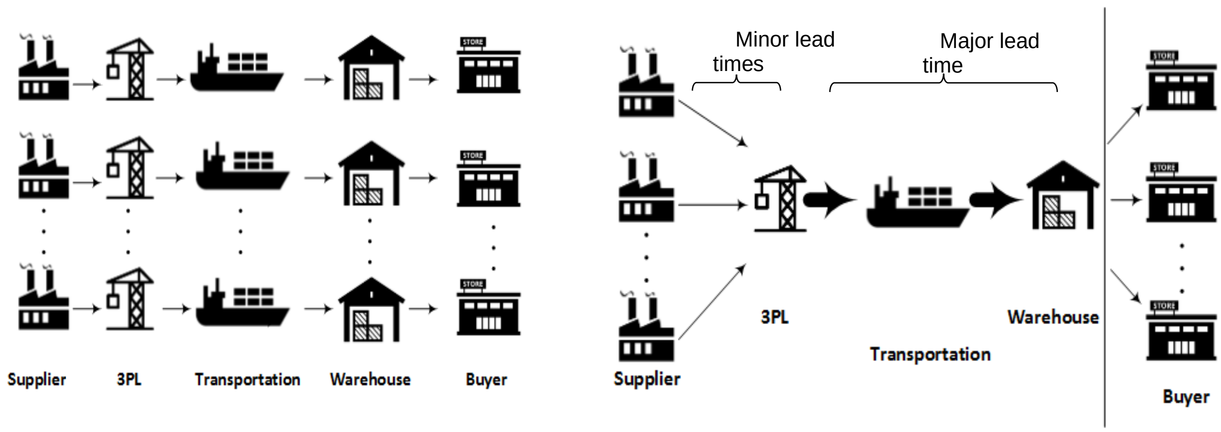


Figure 4-1: Individual replenishment method (left) vs. Collaborative method (right)

For the sakes of contrast, Figure 4-1 on the left side depicts the individual method for replenishment, where a single buyer (i.e., importers) individually restock inventory from a single vendor who delivers cargo through a Third-Party Logistic (3PL) provider in charge of sending the cargo to the importer's destination. Such method applies for a given subset out of all feasible buyer-vendor combinations, directly shipping end-to-end individual cargo of size and constraints each importer can afford. Alternatively, the proposed collaborative method (a representative of the S-CJRP) features coordination between buyers (Figure 4-1 on the right side). It starts with multiple cargo deliveries from the different suppliers synchronized to a 3PL company in charge of consolidating incoming cargo into a single order destined to a convenient location close to the partnering buyers. Such buyers (importers) or "players"[2], restock inventory with a frequency Tk_i, in amount of $Q_i = D_i\, Tk_i$, where k_i is an integer and D_i is the demand of the i-th item family. Again, the consolidated cargo is sent to a destination (i.e., a port) near to the importers facilities who work as a "coalition"[*]. Furthermore, importers share storage facility and costs. The scope of the proposed collaborative method currently does not include the

[2] in terms of Game Theory

breakdown of the cargo flow back to separate family items, assuming short-range movements to its final destinations.

4.2.2 S-CJRP limiting assumptions discussion

In Chapter 3 was proposed a heuristic solution approach to the S-CJRP that assumes stationary demand and normally distributed forecast errors. In addition, the S-CJRP approach considers finite capacity of transportation units and warehouse space, also allowing for multiple vendors and buyers interactions. The S-CJRP approach is distinctively a JRP stochastic version that incorporates the Shapley Value function to allocate both collaboration costs incurred by each colluding company (players) and gain shares. The main assumptions considered for the model are listed below:

1. *The replenishment lead time is fixed and the difference between the vendor lead times is insignificant.*
2. *Fixed multiple buyers, products and vendors are considered.*
3. *Demand forecast error is stochastic (normally distributed).*
4. *Limited warehouse capacity.*
5. *Limited and homogenous transport capacity.*
6. *The cargo is compatible and non-perishable.*
7. *The players agree to use the Shapley Value as an allocation method.*
8. *Shortage is not allowed.*
9. *Quantity discounts are not available.*

Through hundreds of tests, in Chapter 3 was demonstrated the S-CJRP model potential to deliver substantial savings in real settings. Although pragmatically oriented, such work did not sufficiently covered for useful policies and guidelines to deal with frequently observed real-world affairs. Therefore, this work takes a closer look to the model assumptions, in search of most serious limitations that could undervalue its implementation. This work rethink potential issues related to former assumptions 1, 2, and 4 in order to improve the understanding of S-CJRP's usefulness and to anticipate valuable policies for practitioners.

The author acknowledges that the S-CJRP model is imperfect; the expected value of the cost delivered by the model could be imprecise if compared to the actual value obtained in practice once it is used. It should be considered that in practice various situations could arise that could affect the cost positively or negatively. Even so, its use offers some effectiveness, superior to the usual trial and error used in practice, even more by SMEs, It is necessary to declare that this work does not intend to modify the mathematical model of the S-CJRP, but in recognition of its imperfection, it analyze situations that could affect its functioning in practice.

In its original version, the S-CJRP neglects the stochastic nature of some minor transports, thus limiting the model's ability to represent reality. Regarding the first assumption, the lead time is indeed a stochastic variable; moreover, in actual settings the lead time could have enough variability to considerably affect the inventory replenishment schedule, hence imposing a higher optimal base-stock level to mitigate shortages (Song, 1994). In practice, and in particular in Colombia, it was observed in Chapter 2 that exists a significant variability in the lead time. In practices there are many noncontrollable factors that affect both import and export times, and as consequence the replenishment cycle. The disregarded lead time variability could affect the coalition savings, which for the present work motivates to split the model lead time into two separate transports (see collaborative method, to the right of 4-1): a first set of transports, between the suppliers and the 3PL, with its corresponding *minor lead times*; and a subsequent and unified transport between the 3PL and the warehouse, with its *major lead time*. This separation allows for taking into account diverse transport modes and travel conditions with differential *minor lead times*, not previously considered.

Concerning the second assumption, Chapter 3 considered that multiple buyers and vendors are engaged in associated working but taking as granted the coordination mechanisms for their interaction. Particularly in the present research, coordination is taken as a most sensitive real-life condition since lack of it could generate extra costs, as discussed in coming (Section 4.4.3). The lack of coordination results in non-compliance with replenishment schedules, which in practice compromises S-CJRP approach ability to achieve the expected savings. As for the individual case, the consequences of poor management do not affect other than the same player. Conversely, for the collaborative case inadequate coordination could affect the savings of more than one party, turning it into a less attractive and unstable option. Because of the former, we seek to explicitly consider coalition coordination mechanisms in our present work

As well related with the second assumption, the number of players of a coalition is actually dynamic and changes over time. After a successful S-CJRP initiative it seems natural that some other players would want to be part of it, thereby pushing changes in inventory policies, warehouse capacities, requiring additional investments, and of course, altering the coalition surplus. The aforementioned considerations deserve deeper analysis, with a high potential to enhance S-CJRP continued use and as a source of useful policies for practitioners.

Finally, and relative to assumptions four and five, the original model analysis falls short in examining the implications of increased capacity through collaboration. Although the authors mention that the model has potential to reduce the cost and to leverage the capacity expansion investment, they fail to explain such mechanisms. A greater understanding is needed on how the S-CJRP approach through economies of scale from collaboration can provide a superior financial option than individual investment.

4.2.3 Recalling the S-CJRP model

Next, it is presented the mathematical foundation used in this research, essentially the same as in Chapter 3, except here the lead time is decomposed in two parts: *minor lead time* Lm_i time and *major lead time* LM. However, this does not produce any change on the model since the parameter *Lead Time* is still considered as deterministic instead a stochastic variable. Recall that the goal is to verify that using the S-CJRP In addition, the original model takes the minor lead time as deterministic, while in this work the minor lead time is considered normally distributed, as well as the major lead time. The model notation is defined as follows:

TC	*Total annual cost (ordering, holding and transportation cost)*
M_s	*Set of family items* $M_s = 1,2,3, \dots, M$
N_s	*Set of players* $N_s = 1,2,3, \dots, N$
n	*Number of item families,* NxM
I	*Set of family items/players pair* $I = \bigcup_{y \in M_s, z \in N_s} (y, z) = \{(1,1), (1,2), \dots, (1, N), \dots, (2,1), (2,2) \dots (2, N), \dots, (M, N)\}$
D_i	*Annual demand rate for the item* $i, i \in I$
Lt_i	*Total lead time* $i; i \in I$ *(minor lead time plus major lead time)*
σ_i	*Standard deviation for the item* $i, i \in I$
$Z_\propto$	*Security level*
S	*Major ordering cost*
s_i	*Minor ordering cost for the item* $i, i \in I$
T	*Time between two consecutive replenishments*
h_i	*Holding cost for the item family* $i, i \in I$
k_i	*A positive integer multiple of* T *for the item* $i, i \in I$
A	*Cost of a full transport/container unit*
W	*Maximum capacity of a transport unit*
w_i	*Weight/volume per unit of item* $i, i \in I$
H	*Maximum storage capacity available*

Recall, the proposed objective function is composed by three components. The first one refers to the annual ordering cost, the second represents the annual holding costs and the last one refers to the annual transport cost. By adding these components, the objective function is expressed as follows:

$$Minimize: \; TC(T, k_1, k_2, \dots, k_n)$$

$$= \left(S + \sum_{i \in I} \frac{s_i}{k_i}\right)/T + \left(\frac{T}{2} \sum_{i \in I} D_i k_i h_i + \sum_{i \in I} Z_\infty \sigma_i h_i (\sqrt{Lt_i + Tk_i})\right) + \sum_{i \in I} \left(\frac{w_i D_i A}{W}\right) \quad (4\text{-}1)$$

$$Subject\ to:$$

$$\sum_{i \in I} D_i w_i T k_i + \sum_{i \in I} Z_\infty \sigma_i w_i (\sqrt{Lt_i + Tk_i}) \leq H \quad (4\text{-}2)$$

$$\forall i \in I$$

$$T > 0; \;\; K_i: integer$$

Constraints in (4-2)

(3-6)are concerned with the warehouse finite capacity. It should be noted that the objective function in (4-1) depends on the variables T and k_i. For a single product case ($n = 1$) the expression in (4-1) must be modified not considering the s_i and k_i.

4.3 Solution approach

This section illustrates the developments disposed to respond the S-CJRP supplementary issues that motivates this research. First, it is introduced the overall proposed solution approach called the DES augmented S-CJRP, which incorporates discrete-event simulation techniques as an improvement and extension of the S-CJRP's solution heuristic. As part of the former, it also illustrates the original S-CJRP's heuristic solution procedure (Otero-Palencia, Amaya-Mier, & Yie-Pinedo, 2018), which concludes with a Shapley Value function evaluation of a combinatory of capacitated JRP results from a genetic algorithm.

4.3.1 A DES augmented S-CJRP

In order to explore three supplementary issues to the original S-CJRP version that motivates the present research, responses obtained from the S-CJRP heuristic introduced in Chapter 3 were reproduced and enriched by means of discrete-event simulation (DES). In this way, further enhancing the model and incorporating both variables and features that enabled a subsequent sensibility analysis. Figure 4-2 illustrates the proposed general functioning schema. This procedure begins with the scenario generation composed of random parameters combinations of the model expressed in (4-1). Note that each scenario corresponds to an instance of the problem. In the second step, the generated instance is solved by means of the S-CJRP heuristic approach. In the third step, the second step output (T, k_i) is the main input to reproduce the functioning of the supply chain coordination between buyers using DES, also the parameters created for those instances are kept. Finally, is calculated the cost allocation for each placer using the Shapley Value function. The DES augmented S-CJRP model re-creates the S-CJRP solution, but it also incorporates further variability in improved process modeling and variables, such as in the suppliers' minor lead times prior to the cargo merging point (see Figure 4-1 and Figure 4-3), the consolidated international shipment plus the in land transportation at destination or major lead time, cargo arrival and storage times, and both holding and ordering costs. A more detailed description of the second step comes in the next section, followed by a description of cost reductions achieved and the savings allocation using the Shapley Value.

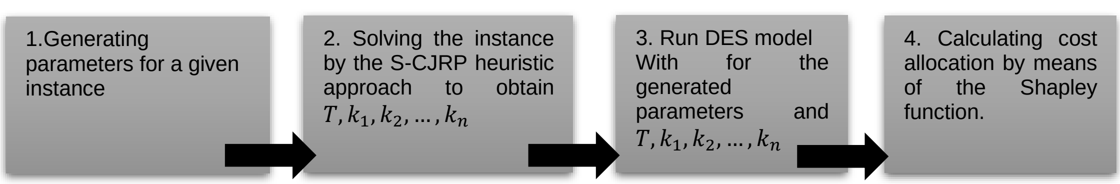


Figure 4-2: Steps of the solution approach coupling S-CJRP heuristic and discrete-event simulation

4.3.1.1 S-CJRP heuristic approach

The S-CJRP is solved using the heuristic approach proposed in Otero-Palencia, Amaya-Mier, & Yie-Pinedo (2018) such as follows:

$\boldsymbol{Step\ 1}: Determine\ all\ possible\ coalitions\ C_i\ over\ N$

$\boldsymbol{Step\ 2}: For\ i = 1 \ldots 2^{|N|-1}$

$Calculate\ V(C_i)\ using\ a\ Genetic\ Algorithm\ , with:$

$D_j, h_j, W, w_j, S, s_j, A, \sigma_j, z_j, H, where\ j = 1,2,3, \ldots, |C_i|$

$\boldsymbol{Step\ 3}: Calculate\ the\ Shapley\ Value\ using\ all\ V(C_i)$

The Step 1 concern is determining all possible coalitions that can be formed out of the initial set of players (N), for our purposes: $2^{|N|-1}$ different ones. The Step 2 consists of solving an equal number of instances of the S-CJRP by means of the genetic algorithms proposed by Otero-Palencia, Amaya-Mier, & Yie-Pinedo (2018) and illustrated in Figure 3-4 in Chapter 3. Finally, the Step 3 consists of calculating the Shapley Value (Shapley, 1953) using the S-CJRP solved instances from the Step 2, which provides a fair distribution that allocates the coalition obtained benefits after the expected marginal contributions of its players; the total average contribution is obtained from the contributions of all possible coalitions that can be formed.

4.3.1.2 The DES model

As mentioned before, the S -CJRP model has not been modified and its solution is the basis for the design of the interest inventory policies. The proposed DES model basically emulates the behavior of the operation of such inventory policies in practice, including the variation of demand and the supplier lead times. This model broadly does three things: first, it simulates the generation of daily demand by customers. Second, it simulates the inventory revision and replacement process each replenishment cycle, and finally, it simulates the logistical coordination and consolidation process, and the cargo delivery to the shared warehouse. It is in this last process where the lead time and costs variations that are of interest in this extension are presented.

As expected, due to the variation of the actual inventory process and the design of the model itself; which is designed to meet the demand for a specific service level, differences are expected in the real cost in the short term (say a few years) and expected cost provided by the model, however, more importantly, the objective is to verify if the surplus promised by collaborative strategy still persists. To compare the actual performance of the inventory policy provided by the S-CJRP model and the actual results, the model computes a function with the previously described cost variables and model parameters.

In addition to the notation presented in Section 4.2.3, the next notation must be considered for understanding of the next expressions.

$\ddot{TC}_c$	$Total\ effective\ annual\ cost\ for\ the\ coalition\ (ordering, holding, transportation\ cost)$
$\ddot{TC}_{N_s}$	$Totaleffective\ annual\ cost(ordering, holding, transportationcost)\ for\ player\ N_s$
K	$Total\ effective\ number\ of inventory\ replenishments$
$\dot{k}_i$	$Effective\ number\ of\ inventory\ replenishments\ for\ the\ item\ family\ i$

$\dot{q}_i$ *Sum of the effective number of units replenished of the item family* i
$\ddot{q}_i$ *Sum of the effective number of units kept in security stock of the item family* i
$\ddot{d}_i$ *Sum of the effective number of lost sales of the item family* i $for\ the\ individual\ method$
$\hat{d}_i$ *Sum of the effective number of lost sales of the item family* i
$\dot{\varphi}_{N_s}$ *Individual cost for player Ns, assigned by the Shapley function*
t *Current simulation time*
O_i *Order signal,* $O_i \in \{0,1\}$
P_i *Inventory position of the item family* i
SS_i *Security Stock:* $SS_i = Z_\infty \sigma_i h_i(\sqrt{Lt_i + Tk_i})$

The total cost obtained by the simulation model is computed as follows in expression (4-3) for each player using the individual method:

$$\ddot{TC}_{N_s} = \mathrm{SK} + \sum_{i \in M_s} s_i \dot{k}_i + \frac{1}{2} \sum_{i \in M_s} \dot{q}_i h_i + \sum_{i \in M_s} \ddot{q}_i h_i + \sum_{i \in M_s} \frac{w_i \dot{q}_i A}{W} \tag{4-3}$$

Now, the total effective cost for the coalition (using the collaborative method) is described by the next expression:

$$\ddot{TC}_c = \mathrm{SK} + \sum_{i \in I} s_i \dot{k}_i + \frac{1}{2} \sum_{i \in I} \dot{q}_i h_i + \sum_{i \in I} \ddot{q}_i h_i + \sum_{i \in I} \frac{w_i \dot{q}_i A}{W} \tag{4-4}$$

The expected percentage of savings per player ($\rho_{N_s}\%$) are calculated as follows:

$$\rho_{N_s}\% = \left(\frac{\dddot{TC}_{N_s} - \dot{\varphi}_{N_s}}{\dddot{TC}_{N_s}} \right) * 100 \tag{4-5}$$

In Figure (4-3) is described as the simulation logical model. The *demand generation process* consists of the arrival of the daily orders for each product to the retailer. When an order can be fulfilled, the inventory is discounted, but if the inventory position (Pi) is less than the demand order, such order is accounted for as a lost sale.

The process of *replenishment cycle time check* consists of verifying day-by-day if the current simulation time corresponds to the date on which a resupply must be carried out. So, if the difference between the current simulation day, and the day on which the last replenishment was performed for item i is greater or equal to Tki (converted to days) then, a resupply signal is sent to the supplier. Then, all products with a replenishment signal ($O_i = 1$) are ordered in an amount equal to $q_i = D_i Tk_i + SS_i - P_i$. Suppliers take orders and deliver them to the 3PL. Note that at this point each product could have a different delivery time, however, the longest lead item of the order in the replenishment *"lead"* the delivery time. This time counts as the minor lead time. Later, the cargo is consolidated and shipped via sea to the destination port, where it is then transported to the final warehouse. Note that in this section all products are together, so all of them have the same lead time, known as the major lead time.

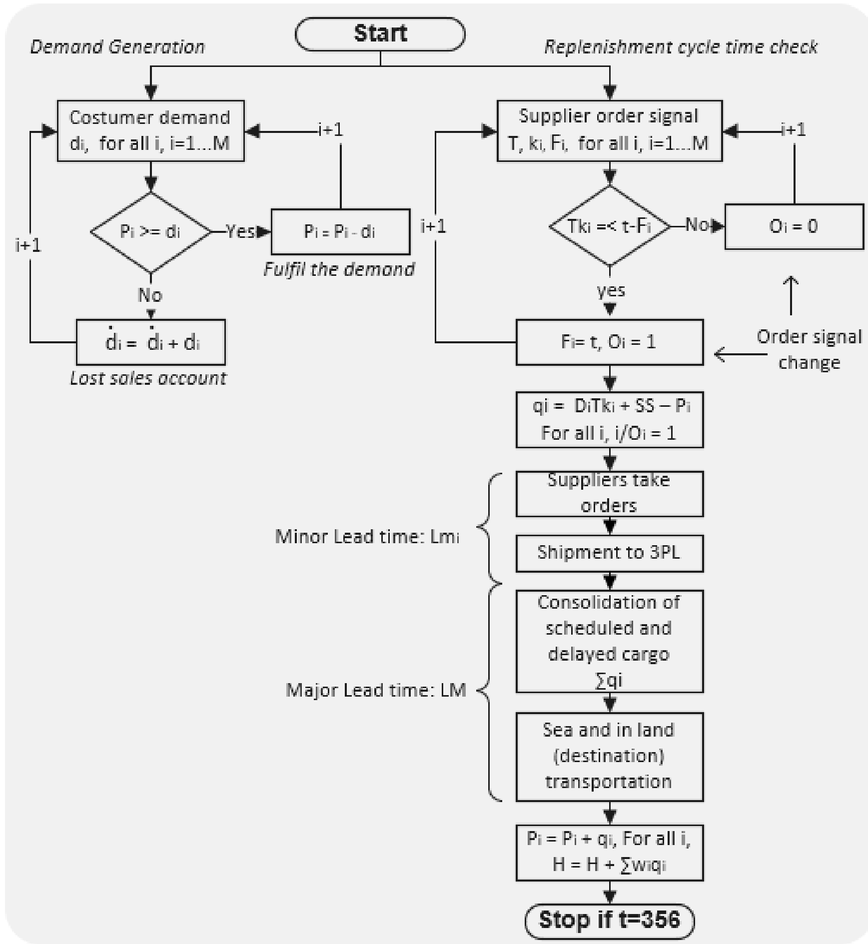


Figure 4-3: Logical model of the inventory replenishment process

In the absence of randomness in lead times, the cost delivered by the simulation model is statistically equivalent to that of the optimization model. I.e., $TC = \ddot{T}C_c$. In such a case, the replenishment scheduling provided by the optimization model is fully met. Note that the effect of the randomness of the lead times simulated in the DES model falls on such programming. Due to a policy imposed on the model; the 3PL consolidates all available cargo from suppliers until before the scheduled shipment date (performed in the block *Consolidation* of scheduled and delayed cargo in Figure 4-3). This policy aims to preserve the agreement previously made between the players and thus avoid opportunity costs for lost sales (although do not accounted). A similar policy is followed for the individual case; all delayed cargo must be shipped later incurring extra costs. A further discussion about the economic effect of the delays in the delivery to the 3PL is provided later in Section 4.4.3.

4.4 Results

This section aims to address the four main complementary issues mentioned early in the introduction, illustrating with numerical results and subsequent analysis including managerial insights. The section initiates illustrating through a numerical case the effect of unexpected changes of both lead times and costs over the players' savings when the surplus is allocated with the Shapley value function, as a contrast to the linear allocation method commonly used in practice. With this, the section provides recommendations on the selection of players prior to the coalition formation and on uniformity on cargo features that facilitates agreements acceptance. Next, it follows a numerical case exposing S-CJRP collaborative inventory cost management in SME's as more affordable means to achieve greater economies of scale than individual capacity investments. Subsequently, through an example it is shown the economic impact of the lack of coordination on a model instance, providing with directions whether to internally coordinate the joint ordering or if S-CJRP favors outsourced coordination. Finally, it is proposed a case and strategies to manage the entry of new players into an already established coalition and propose a newcomer entry fee.

4.4.1 S-CJRP cost reductions and surplus allocation

Discrete-event simulation (DES) provides with the means for extending the modeling assumptions closer to reality, as well as for creating variated tests settings to appreciate the behavior of the model in both favorable and unfavorable scenarios, thereby increasing our knowledge on the applicability limits of the S-CJRP approach, weak spots and/or strengths. Favorable scenarios refer to situations in which demand increases or costs are reduced, while non-favorable refers to the opposite case. In this section, we will illustrate with a numerical example the S-CJRP potential for cost reductions contrasting it with an alternate order consolidation method, in order to demonstrate not only its savings potential but the additional advantage of our proposed surplus allocation method.

This study first exemplify S-CJRP potential for cost reduction. Otero-Palencia, Amaya-Mier, & Yie-Pinedo (2018) contrasts two methods for cargo consolidation: S-CJRP consolidation and LCL consolidation, against the non-cooperative individual base case to determine the relative savings obtained from both cargo consolidation methods. Both methods equally use the capacitated JRP and deliver a joint replenishment operation managed by a 3PL, hence obtaining identical global cost reduction. Yet, the two methods use different ways to allocate the surplus: S-CJRP method uses the Shapley Value function, while Less-Than-Container (LCL) linearly allocates charges per player proportional to the cargo size added to the coalition. Otero-Palencia, Amaya-Mier, & Yie-Pinedo (2018) showed that the S-CJRP outperforms LCL consolidation, since the latter allowed for asymmetries between surplus allocation and cost reduction impact: players who contributed more significantly to the coalition cost reduction could achieve lower savings, with minor marginal advantage; conversely, those with a smaller contribution could receive higher savings, turning the gainshare uneven and collaboration unattractive. On the other hand, the S-CJRP consolidation is fairer, allocating savings after the players' expected cost reduction marginal share. Hence, coalitions derived from the S-CJRP consolidation are more likely to be accepted, thus implemented.

To verify the effectiveness of the proposed approach over a variety of scenarios, the DES augmented S-CJRP model was tested by varying the S-CJRP parameters shown in the equation in (4-1). 110 replicas were produced for each scenario, and 300 scenarios were created, all of them with 4 players. I.e., the DES model was run 110 times with the same parameters. Three sizes of item families $n = 10, 15,$ and 20 were considered (50 over 300 scenarios were created for each n). Four different values for the mayor cost (S) were fixed (100, 200, 300 and 400) and the minor cost (s_i) was defined as a function of the mayor cost $(0.05 * S,\ 0.1 * S, 0.3 * S, 0.5 * S, 0.7 * S, S)$, all monetary units in USD. The Demand (D_i) was considered normally distributed with parameter mean ($\bar{x}_i$) and standard deviation (σ_i), however in each case the mean was selected randomly from the range [1000, 100000]. To avoid unrealistic scenarios, such as extremely greater standard deviations than the demand mean, the standard deviation was selected considering a coefficient of variation ($Cv = \frac{\sigma}{|\bar{x}|}$) in the range [0.05, 0.15]. Also, to avoid nonrealistic holding cost (h_i) it was defined as function of the mayor cost as $[0.01 * S, 0.15 * S]$. Transport cost (A) and unit transport capacity (W) were fixed in $80 USD/trip and 76 cubic meters, respectively. The volume per unit of item w_i is assumed analogous among all players and therefore uniformly was set to 1. The parameter Z_α was fixed in 1.64 ($\alpha = 0{,}05$) and the lead time was considered normally distributed but composed by two main parts. A minor lead time between the suppliers and the 3PL and a mayor lead time between the 3PL and the warehouse. For the former, the mean was chosen from the range [1, 2] weeks and the second in the range [2, 4] weeks, with a coefficient of variation in both cases in range [0.05, 0.15]. Note that the choice of model lead time has a direct impact on its expected costs. In real settings, if the effective lead time of a family item exceeds the date on which the replenishment must be carried out, then such items must be shipped later increasing ordering costs. Knowing that the lead time follows a normal distribution, the mean of the longest lead time plus three standard deviations could be chosen as the parameter value to reduce the risk to zero. However, that would imply increasing the safety inventory, therefore assuming a reasonable risk could be convenient, nevertheless, this work does not intend to discuss such details. In this case, it is considered a probability of exceeding the lead time established as a parameter of between 0.00135 and 0.3, which corresponds to 3 and 0.52 standard deviations to the right of the normal distribution, respectively. The Maximum coalition storage capacity available (H), or warehouse capacity constraint, was calculated considered the minimum capacity required when acting together. Such space is the expected cargo volume for each player when the JRP model orders multiple items and does not consider capacity constraints. Since the scenario generation is completely random, some scenarios were discarded when resulting in unreal/impractical parameter combinations. For the individual cases (regular non-collaborative method), it was necessary to generate a warehouse constraint (H_0) for each player, with the rest of parameters kept as formerly described. As for the coalition case, the holding and major ordering costs are calculated as the average of values observed in the individual cases before forming the coalition. This approach is conservative, but in a real setting ordering and holding costs are expected to be lower when the cargo volume increases due to discounts offered by 3PLs.

Table 4-1 shows the numerical results of a 4-player collaboration case contrasting both consolidation methods against the individual method. The fourth row shows the total cost of players using the individual method, adding up to an overall amount of $ 8116 per year. In other hand, both cargo consolidation methods yield the same total cost of $ 6192, therefore equally yielding a cost reduction of $ 1920 per year. Furthermore, the LCL consolidation savings depend on the cargo size. For instance, Player 1 adds 12,000 cubic meters of units per year, meaning the 52% of the overall cargo. Thus, in LCL consolidation Player 1 is linearly responsible for 52% of the total cost ($ 3232), thereby obtaining such percentage of the savings from the collaboration. On the other hand, the S-CJRP consolidation method using the Shapley function allocates cost to Player 1 in the amount of $ 2811, noting that the individual base case cost of $ 3312 exceeds both. The difference between the base case and S-CJRP consolidation is 15.1% while with the LCL consolidation is 2.4%. For Player 1 the LCL consolidation could appear unattractive by its minor retribution, and probably would not be part of that coalition. The LCL method consistently appears less attractive for big players, previously handling large cargo volumes, since their returns are not significant nor coherent with their investments. Alternatively, the S-CJRP improves Players 1 and 2 benefits (who owns 87% of the cargo), both significant contributors to the overall cost reduction. Although Players 3 and 4 will prefer the LCL option, such coalition is not acceptable to Players 1 and 2, whom would not be part of it in the knowledge of the S-CJRP improved benefits. Therefore, is left there only feasible room for the S-CJRP consolidation since reasonable for all players and perceived as fairer. In this case, due to the variability of lead time, the coalition had to incur an additional replenishment for delayed cargo, while for individual cases only players 1 and 2 incurred additional replenishments. Lost sales when using the collaborative model were 4%, 5%, 6% and 6% for players 1,2,3 and 4 respectively. Overall, the collaborative model is more convenient than the individual method since the risk and costs associated are shared between all the players.

Table 4-1: Summary results of comparing LCL and S-CJRP consolidation for 4 players

	Player				
Parameters	***1***	***2***	***3***	***4***	***Total***
Demand (units/yr.)	12000	8000	2000	1000	23000
Standard Dev (units/yr.)	400	200	150	100	***
k_i	1	1	2	2	***
Individual base case ($/yr.)	3312	2847	1234	723	8116
LCL consolidation ($/yr.)	3232	2155	539	269	6196
S-CJRP consolidation ($/yr.)	2811	2140	866	379	6196
Savings S-CJRP Consolidation (ρ_{N_s}%)	**15.1%**	**24.8%**	**29.8%**	**47.6%**	***
Savings LCL consolidation (ρ_{N_s}%)	2.4%	24.3%	56.3%	62.7%	***

***** Does not apply**

In another hand, Table 4-2 shows results for 4 players using only the S-CJRP consolidation method since superior, as was formerly shown, but now increasing the overall number of item families jointly ordered in 10, 15 and 20. Additionally, the item families share per player is distributed according to two scenarios: S1 and S2; featuring respectively, a quasi-evenly and unevenly item distribution added to the coalition by the players. The expected savings values of using the S-CJRP approach are listed in rows on the right side of the Table 2. Considering the evenly item-share scenario (S1) for a 10-items family, players 1, 2, 3 and 4 could in turn achieve savings of 30.1%, 29.1%, 27.3% and 25.4%, respectively. These percentages represent the relative savings when contrasting the costs of the proposed collaborative method over the individual method's costs.

Table 4-2: Results of the model for 4 players.

Number of item families (n)		Item families per player				Average Savings (%) S-CJRP				
		P1	P2	P3	P4	P1	P2	P3	P4	*Row Average*
10	*S1*	2	2	3	3	30.1	29.1	27.3	25.4	*27.9*
	S2	1	1	4	4	43.1	38.2	17.2	21.2	*29.9*
15	*S1*	3	4	4	4	33.2	28.1	25.4	26.2	*28.2*
	S2	1	2	6	6	44.1	36.3	20.1	21.2	*30.4*
20	*S1*	5	5	5	5	25.5	23.5	28.3	29.6	*26.7*
	S2	1	1	9	9	37.2	33.5	17.3	20.0	*27.0*

In all instances, the S-CJRP approach consistently yields savings under the parameters in which it was tested. However, it should be noted that there are some scenarios where the viability of forming a coalition increase. I.e., the S1 scenarios always yield a more evenly distributed savings than under S2. When players contribute with similar cargo volume, their benefits are also comparable since they all benefit from a similar increase in scale. E.g. for $n = 20$ and scenario S1, the item distribution between players is identical (5 items per player), so their expected saving allocations are close: 25.5%, 23.4%, 28.3% and 29.6% for the players P1, P2, P3 and P4 respectively. Conversely, the item distribution between players in scenario S2 on the following row is imbalanced: both P1 and P2 manage only 1 element, while players P3 and P4 manage 9 items each. Thus, it makes sense that P1 and P2 reach greater benefits from colluding; 37.2% and 33.5% respectively, since they achieve a greater scale increase than P3 and P4; 17.3% and 20% respectively, who already managed a large cargo volume. This situation can be verified on the rest of the scenario couples S1 and S2 for 10 and 15.

Nonetheless, considering the row savings average for each scenario (rightmost column vector); it could be thought that S2 outperforms S1 scenario since always featuring higher averages. However, care must be taken since such S1 higher averages are due to the large savings from the players who contribute with little cargo volume but colludes with big players, thereby benefiting from unproportioned economies of scale. These large savings inflate the (simple) average computation. On the other hand, the S1 scenario homogeneity facilitates and increases the chances for agreements acceptance, since naturally players sense a more evenly benefit allocation.

Partners' selection prior to the coalition formation is a key element to the success of this collaboration approach. It is recommendable that cargo features (demand and cargo volume) between players should be as uniform as possible, since it is simpler to negotiate an agreement between players that receive comparable savings.

4.4.2 Breaking capacity constraints with collaboration

This section introduces an analytical example where three importer companies (players) form a coalition, with the purpose of analyzing the collaboration benefits over the inventory cost management in SME's in the presence of finite capacity and financial constraints.

The three players' mayor ordering cost (S) and transportation cost (A) in USD are $1000 per joint order and $150 per trip, respectively. Each one expects to maintain a 95% service level ($z = 1.64$) and their transport capacity is 76 cubic meters each. The lead time is the same for all players: 2 weeks (0.038 years). Without considering collaboration, each player has an individual capacity warehouse of 200 m^3. Supplementary input for the analytical example is listed in Table 4-3.

Table 4-3: Data for analytical example

Player	D_i	s_i	K_i	h_i	z_i	σ_i	Lt_i	w_i	B_i
P1	10000	150	1	1	1.64	450	0.038	0.125	200
P2	8000	140	1	1	1.64	400	0.038	0.125	200
P3	5000	155	1	1	1.64	380	0.038	0.125	200

For practical effects, only the results obtained for players P1 and P3 are discussed, since results for P1 and P2 are analogous. Figure 4-34-3 shows the inventory cost behavior relative to the player P1. *Curve P1.R* features the individual method considering warehouse capacity constraints, where P1 could only achieve a minimum cost of $11,166 (at (1), in USD/yr.), given his finite warehouse space limiting a larger and potentially economical amount **of orders over the planning horizon. Notice that P1 could reduce his management inventory** cost to $7.448 (33% reduction at (2), where T is close to 0.43) if he acquires extra warehouse capacity for a total of 600 cubic meters. That is shown in the *curve P1* which characterizes the optimal and unrestricted individual behavior cost. For a stand-alone company, especially a SME, expanding its warehouse capacity could be a beneficial, yet unfeasible option. Thus, the difference between the minimum feasible cost (1) showed by *curve P1* and the inflection point (2) of *curve P1.R* is $3.718, which can be considered as an opportunity cost.

However, forming a coalition of players P1, P2 and P3 as shown in *curve P1.C* of 4-3, enables P1 to further reduce his inventory cost granted an expanded warehouse capacity but with a lower investment, since now they all share capacity, investment, ordering and holding costs. The expected annual inventory cost achieved under the collaboration method is $6,481, $5,200 and $3,289 in USD/yr. for P1, P2 and P3, respectively. Under the best cost conditions found at (3), P1 could reduce his cost in $4,685, reaching a total saving of 42% when compared with the individual method.

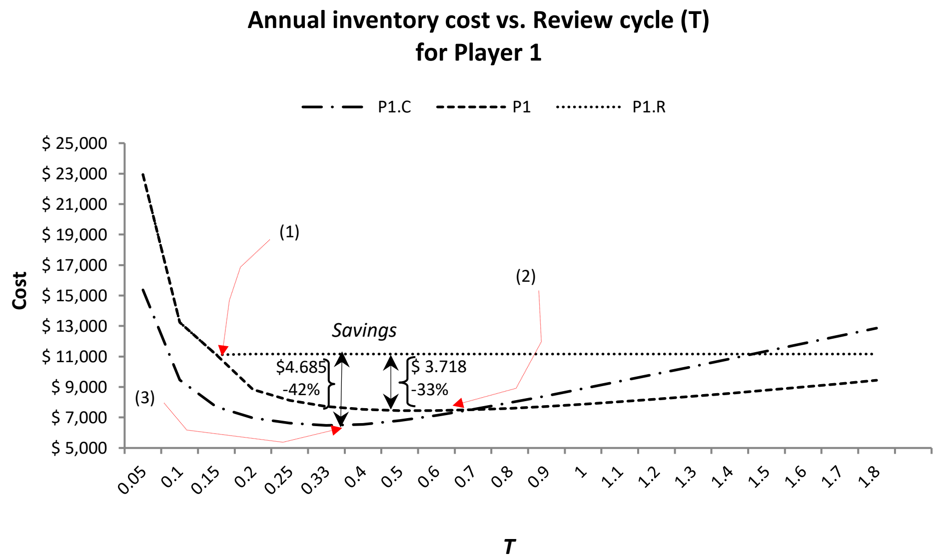


Figure 4-3: Total cost comparison between the collaborative method and the individual method for P1

Similarly, Figure 4-44-4 shows the results obtained for player P3. If P3 acquires additional capacity, she could reduce her costs up to $ 4898 (21% less) when compared to the minimum inventory cost attained through the individual method ($6193). However, by entering into the coalition, player P3 could reach an even higher cost reduction towards $3289 (47% less). Even if P3 had enough individual warehouse capacity, the collaborative agreement featured in *curve P3.C* will be a more attractive option, provided expected savings in the amount of additional 33% at (2). Player P3 takes advantage from the higher volume of cargo jointly managed with P1 and P2. From her perspective, P3 reaches a larger economy of scale, now feasible since both the mayor ordering cost and the warehouse capacity investment is shared between all players. The inventory cycle could be reduced for some players and increased for others. In addition, the transport capacity is used more efficiently. However, the model finds an equilibrium that warrants a reduced cost. For example, P1 orders 7.7 replenishments per year with a strong restriction of capacity in the current state, while P3 only orders 4. Therefore, they should fulfil three joint replenishments per year, when performing as a coalition.

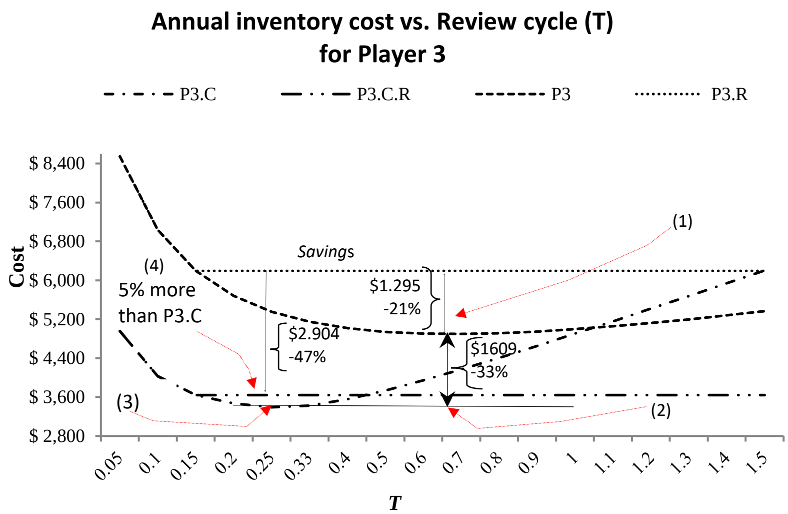


Figure 4-4: Total cost comparison between the collaborative method and the individual method for P3

Through the individual replenishment method, players could reach local optima as long as they expand their warehouse capacities. The individual required spaces for the players P1, P2 and P3 are 600, 508, and 424 cubic meters respectively, for a total of 1,532 cubic meters. However, when working as a coalition, the players only need 1100 cubic meters; 432 cubic meters less than the sum of space requirements required for the players' local optima. The collaborative method not only allows for reducing the total space required thanks to better coordination, but also allows expanding capacity at a lower price, since now they share expansion costs and, they are able to achieve more affordable economies of scale. This feature is especially desirable for companies facing budget limitations, as is the regular case for SME's. In practical settings, the access to volume discounts is difficult for SMEs due to their relative low demand and cargo volume. However, through the collaborative model, SME's can achieve a unified cargo volume attractive to 3PL, enabling players to bargain better prices.

The flat shape of the curve around the inflection point of the S-CJRP model (e.g. the curve P3.C at (3)) allows for reducing the warehouse capacity below the corresponding minimal point of cost, with a reduced impact over the total cost. This typical behavior of inventory models based on the EOQ model (Harris, 1913) is due to the relative insensibility of T over the total cost (Winston, 2003). I.e., the best inventory cost at curve P3.C (at (3)) requires a warehouse capacity of 1100 cubic meters under the collaboration method, for $T = 0.33$ and $k_{1,2,3} = 1$ for all players. However, given that the players for any reason could only afford a maximal space of 700 cubic meters (see curve P3.C.R), the total annual cost would now ascend to $ 16.183, only an additional 5% in excess of the minimal cost in P3.C at (4). Considering that the coalition is 36.4% under the optimal space required (400 m^3 below), it shows insensitivity of the cost function to relatively large departures from the optimal parameters. This feature is desirable for SME's coalitions when the unified optimum capacity is not affordable. Further, it could be a consensual decision when the warehouse rent costs are very high.

4.4.3 Insource or Outsource?

The economic savings, or surplus, derived from the collaborative method can be measured as the gap between the total cost by the individual method minus the total cost by the S-CJRP method individually assigned by the Shapley Value. However, such savings could decrease if the replenishment schedule is poorly executed. E.g., when vendors fail to deliver on time, or buyers are late in ordering, or when the 3PL incurs in any re-processing. All of them are due to lack of coordination, turning an effective supply chain coordination as a decisive matter to reduce cost overruns (Arshinder, Kanda, & Deshmukh, 2008). The coordination task could be in charge of one or several players, even a 3PL, thus assuming the role of 'coordinator'. Such task represents not only a continual spending source, but also a strategic asset allowing for the required coordination and efficiency of the coalition.

Thus, two relevant questions at this point are: how much does the lack of coordination cost? Should the joint-ordering coordination task be insourced within the coalition or outsourced?

To illustrate and answer the questions above, the Table 4-4 shows the data of three players individually facing limited storage capacities (see 10th, 11th and 12th column for initial individual parameters; $\mathrm{B_0}, \mathrm{s_0}$ and $\mathrm{h_0}$ respectively). Expanding the warehouse capacity to the optimum size is desirable but could be cost-prohibitive, since Players 1, 2 and 3 would need an extra capacity of 206, 462, 2281 cubic meters respectively to achieve the optimum. Acting as a coalition under the S-CJRP approach, the players could both negotiate better agreements with 3PL companies as also reducing the individual investment for expanding warehouse capacities. The former is due by the increase in scale provided by the newly formed coalition, which reduces the 3PL charges (i.e., coordinating a joint-order operation in a 3PL facility), while the reduced shared investment is allocated among its members. For illustration, suppose that the coalition reaches a fare reduction of 10% on both the ordering and holding costs by negotiating with 3PLs. For practical purposes, suppose that the same 3PL provides multiple services to the coalition. Some of these items are charged at the mayor cost, such as legalization of cargo, consolidation, storage at source, etc. Other items are charged to the minor cost such as verification of quality at origin, repackaging, marking, etc. The storage at destination is considered a charged item in the holding cost. Note that it is not a general rule that a single 3PL offers all services, it is expected that it will be necessary to establish agreements and contracts with several 3PLs. Thus, the mayor cost (S) is reduced from $\$3500$ to $\$\,3150$, the new minor costs are $s_i = 90, 135$ and 475 for player 1, 2 and 3 respectively, and the holding cost (h_i) is reduced from $\$10\ to\ \$\,9$. Under these parameters and using the DES augmented S-CJRP a good solution is provided by a $T = 0.3048$ and $k_i = 1, 1$ and 2. The individual savings achieved are 26.7%, 32.49% and 47.85% for players 1, 2 and 3 respectively, generating a total annual cost of $ 51,039. Such collaborative inventory policy implies using a replenishment cycle of 4 months for the family items of players 1 and 2, and of 8 months for the player 3.

Table 4-4: Data for insource/outsource example

Player	D_i	s_i	k_i	h_i	z_i	σ_i	Lt_i	w_i	B_0	s_0	c
P1	7000	90	1	9	1.64	350	1	0.25	500	100	10
P2	4000	135	1	9	1.64	250	1	0.5	600	150	10
P3	500	475	2	9	1.64	50	1	2	400	180	10
$T = 0.3048;\ S = 3150;\ S_0 = 3500;\ W = 58;\ A = 150;\ B = 2800$											

The former savings can only be guaranteed if no player misses his/her replenishment schedule. The lack of coordination could increase the total cost considerably. E.g., what would happen if player 1 misses a scheduled replenishment? Suppose this in the context of an order cycle where player 3 does not intervene. As a baseline, assume that player 1 and 2 perform a flawless single joint replenishment cycle, then the incurred total cost without errors would be as follows in (4-6):

$$Total\ joint\ replenishment\ cost\ of\ a\ single\ cycle = \tag{4-6}$$

$$S + s_1 + s_2 + \frac{D_1 T h_1}{2} + \frac{D_2 T h_2}{2} + \frac{w_1 D_1 A}{W} + \frac{w_2 D_2 A}{W}$$

Alternatively, let us now suppose a scenario in which player 1 is late and misses his scheduled replenishment, while player 2 is able to fulfill her replenishment on time. In this case, Player 1 would have to arrange for a later individual order in order to compensate for his lost joint replenishment. Assuming costs remain unvaried, player 1 backlogged dispatch (the right-hand term in the equation) increases the coalition total cost in an amount equal to one mayor cost (S), as it is shown below in (4-7) and (4-8).

$$Total\ joint\ replenishment\ cost\ of\ a\ single\ cycle\ when\ P1\ late \tag{4-7}$$

$$= \left[S + s_1 + \frac{D_1 T h_1}{2} + \frac{w_1 D_1 A}{W}\right] + \left[S + s_2 + \frac{D_2 T h_2}{2} + \frac{w_2 D_2 A}{W}\right]$$

$$= S + Total\ joint\ replenishment\ cost\ of\ a\ single\ cycle \tag{4-8}$$

In this case, this single replenishment cycle cost is increased in \$ 3,150, so the new total annual cost ascends to \$ 54,189 (6.17% more). Note that, no matter which player misses a scheduled replenishment, the total annual coalition cost is penalized at an additional mayor cost for any missed schedule. Then, an underlying question is, who should assume this extra cost? In order to prevent affecting the other players' savings, each late player missing a scheduled replenishment should assume its individual responsibility and afford for the extra cost. Such measure should be considered for inclusion in the coalition management policies. In the extreme, all players could miss their scheduled replenishment. Going back to the previous example, let us suppose both Player 1 and Player 2 missed replenishments. A possible solution for them is to jointly reschedule the replenishment together on a later date. In this case, probably both of them will incur in lost sales but they can still share the mayor cost. Note that players should never skip a replenishment, so as to avoid affecting other players. If they do so, they must assume the inherent costs.

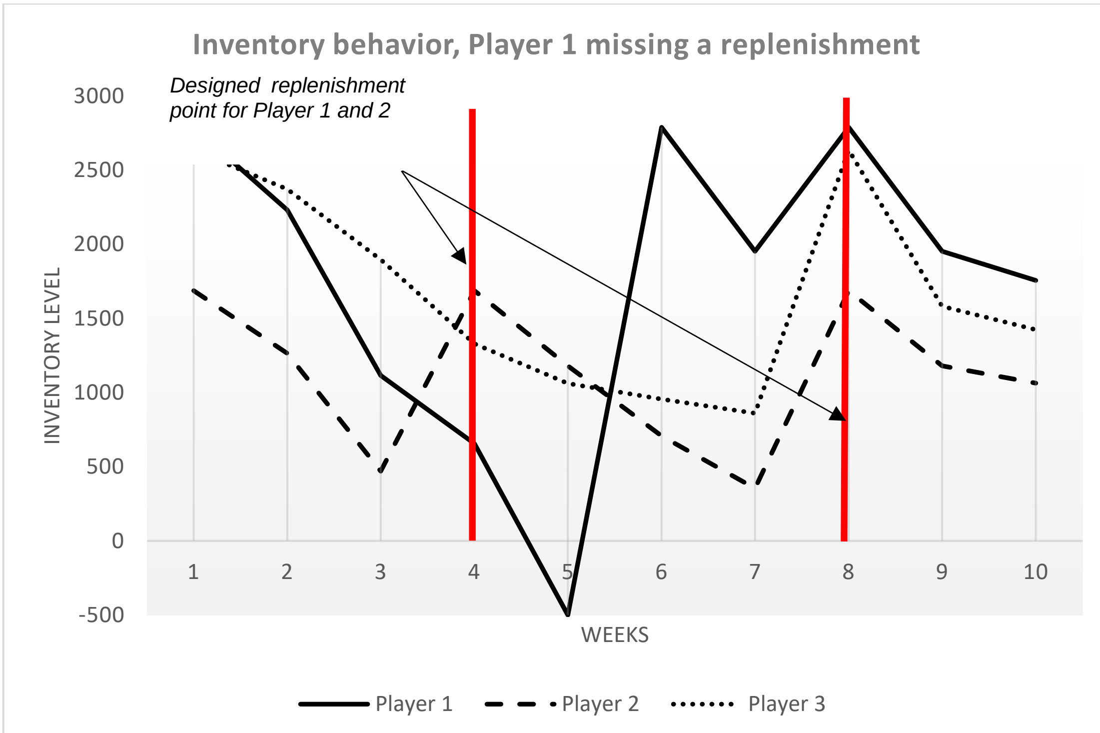


Figure 4-5: Delay effect over the inventory replenishment of a triad of players.

Another issue is regarding the opportunity cost incurred by the inventory shortage. Figure 4-5 shows the delay effect over the inventory level of the current example. Note that in week 4 only player 2 replenishes inventory, while player 1 does his individual belated replenishment of week 4 in week 6. Later in week 8, all players replenish, although the re-stock amount of player 1 is lower than his expected order quantity ($Q_i = D_i T k_i$). Despite the fact that the original S-CJRP model neglects shortage costs, we can define them as an average opportunity cost defined by the profit unit margin ($f = \$10$) multiplied by the number of lost sales (Padmanabhan, Vrat, Padmanabhant, & Vratt, 1990), for the case denoted by the negative inventory value of 500 at week 5. Then the cost per missing is defined as follows in (4-8):

$$Oportunity\ cost = f * 500 \qquad (4\text{-}7)$$

Hence, Player 1 would incur in a total cost by lack of coordination equal to:

$$P1\ total\ miscoordination\ cost = S + f * 500 = \$3{,}150 + \$\ 5{,}000 = \$\ 8{,}150 \quad (4\text{-}8)$$

Since the logistic cost for player 1 acting individually is $ 33,599 and the cost under the collaborative strategy is $ 24,603, the reviewed saving is just 2.5% when accounting for his flawed collaborative performance with a cost increment of $ 8,150. What is more, not considering possible extra holding costs by items kept in custody until the next delivery date at the 3PL's warehouse. From this perspective, collaboration does not look that attractive for player 1.

Analyzing the former, we argue as more favorable to outsource the supply chain coordination, by two main reasons: first, is reasonable to assume a 3PL's already having the experience and the technology (ERP, tracking systems, facilities at site, etc.) to handle the task, thus outperforming any given player undertaking such an unfamiliar task. Second, if the coalition internally assumes the coordination task with proprietary resources, it must also assume the incurred overruns. Outsourcing is an alternative to transfer the supply chain risk, since the coordination role must assume any cost incurred by misguided directions or lack of coordination. Thus, outsourcing could be cheaper and reliable. Still, there remains an underlying question: Is the collaborative model still profitable if the coordination is outsourced?

Since the 3PL market is deregulated and fluctuating, one way to secure this matter is to formulate a policy for players for only incurring in an additional expense not greater than the savings they get from exploiting economies of scale. Thus, all players need to evaluate his economic expectative before forming an agreement. In order to maintain fairness, we suggest that the coordination cost to be paid to the 3PL should be allocated in proportion to the marginal contribution of the players after Shapley. Note that most 3PL fares related to the joint-order process can be easily mapped into the S-CJRP mayor cost (S) and minor costs (s_i) parameters. The coordination cost is an extra charge incurred for assurance of the replenishment schedule accomplishment, it can be considered as a control task. In this sense, support technologies such as ERP[3] or BPM[4] comes in handy. With the growth of the market offer for coordination tasks, such technologies and expertise could turn into an added value offered with no charge as a market differentiator.

In time, it follows that the learning curve lowers because of the continuous operation and cumulative experience, thus reducing the joint-ordering costs of the 3PL. Therefore, such operative cost reduction should be anticipated for fare renegotiation with logistics operators. An uninterrupted and efficient operation could attract additional potential players aiming to reduce their logistics costs, as is discussed in the coming section.

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[3] Enterprise resource planning

[4] Business process management

4.4.4 How to manage the entry of a new player into the coalition?

In time, and after having successfully implemented a given coalition, there could arise the issue of attending an entry request from additional players. Without loss of generality, it will be henceforth considered the entry of a single player at a time, regardless if it is a single firm or a group. The entry of a new player could generate three possible outcomes: (1) reduce the cost for all players, (2) increase the cost for all players, (3) reduce or increase the cost for some players. In any case, one way to calculate how much the coalition improves or worsens is to compare the DES augmented S-CJRP results both with and without the new player. If players act rationally and on free will, none would accept newer conditions where their benefits would be harmed. Since coalition formation implies consensus, then cases (1) and (3) will not be accepted.

Table 4-5 shows an example of an established three-player coalition, i.e.: P1, P2 and P3; but, also examines the effect, as separate cases, of the eventual admission of additional players P4, P5 and P6 into the coalition. The leftmost column indicates the name of the players, followed by a second one to the right denoting the savings that players P1, P2 and P3 obtain as a result of having formed a coalition. The third column represents the first case, where P4 is now admitted to the original coalition. As a result, Player P1 decreases her cost by 4% more, going from savings of 23% to 27%, P2 goes from 34% to 38%, and P3 from 18% to 21%. Additionally, P4 decreases her cost in 22% by entering into the coalition. The fourth column shows the case 2 where P5 player entrance worsens the savings of all the former players, e.g., P1 goes from 23% to 20%, decreasing by 3%; similarly, it happens to the other players. Finally, the fifth column presents the case 3 where P6 entering results in only P1 reducing his cost, from 23% to 24%, out of the initial members.

Table 4-5: Savings' comparison of three newly-formed coalitions by the entry of a new player

Player	% Initial cost reduction	% Cost reduction by case		
		Case 1: P1,P2,P3,P4	Case 2: P1,P2,P3,P5	Case 3: P1,P2,P3,P6
P1	23	27	20	24
P2	34	38	33	34
P3	18	21	15	16
P4	-	22	-	-
P5	-	-	19	-
P6	-	-	-	21

As formerly argued, only case 1 complies with the minimum terms for acceptance since P4 entrance increases the savings performance for all of the initial players. Nonetheless, once the initial players accept player P4 into their coalition, the following question arises: How much must this new player pay for entering the coalition?

To address the former interrogation, first note that the entry of a new player may require some investments. For example, the increase of the cargo volume may require renting and/or the adequacy of extra warehouse space, i.e., acquisition of shelves and other hardware. Even an outsourced coordinator could request an additional payment for the supplementary duties.

Let us term such additional investments as "*newcomer investment*." As a general rule, it is proposed that the *newcomer investment* should be primarily borne by the new player, since her entry triggers those expenditures.

In addition, preceding players could require an extra bonus to the arriving player for her future savings, now possible thanks to the success of their former coalition. If this is the case, we propose to calculate a *prospect savings fee* considering the following expression in (4-9):

$$Prospect\ savings\ fee\ = \frac{new\ player\ \ annual\ savings}{coalition\ discount\ \ rate} \qquad (4\text{-}9)$$

The "*prospect savings fee*" represents the new player's projected savings value in perpetuity (Allen & Allen, 1991; Bierman & Smidt, 2012). Also, it can be interpreted as an advanced payment for projected benefits (Park et al., 2007). The *"new player annual savings"* refers to the individual expected savings, calculated by means of the S-CJRP. The *"coalition discount rate"*, or the expected rate of return, is the interest percentage that the coalition, as a whole, anticipates receiving over the life of an investment. Now, the total entrance fee can be calculated as the sum of the *newcomer investment* and the $prospect\ savings\ fee$ as shows the expression in (4-10).

$$Entrance\ fee = \text{newcomer investment} + prospect\ savings\ fee \qquad (4\text{-}10)$$

Each arriving player should evaluate the expression in (4-9), but now using her own rate of return, to determine his participation convenience. E.g., suppose that the individual logistic cost for Player 4 is $ 35,000/ year, and the potential cost reduction when acting as a coalition is 30% or $ 10,500/year. Considering a coalition discount rate of 40%, then the *prospected saving fee* calculated using the expression in (4-9) is equal to $ 26,250. In addition, considering that the entrance of Player 4 generates an extra cost of $ 5,000, the entrance fee using the expression in (4-10) is equal to $ 30,250.

On other hand, Player 4 should contrast this fee as an alternate investment returning $ 10,500/year, but using his own discount rate. E.g., consider a rate of 35% and after solving the expressions in (4-9) and (4-10) with this rate, the expected *entrance fee* is $ 34,000. Thus, the investment is attractive since her expected present value is larger than the requested fee. Therefore, the Player 4 could expect profits from this investment. Notice that, any rate under 40% makes unattractive the investment. E.g., considering a rate of 42% the results for the expression (4-10) is $ 29,000. Since the requested fee is larger than $ 29,000, the investment is not viable. If in a real case the discount rate is 42% or more and preceding players still want to incorporate aspirant Player 4 to reduce their logistics cost, they should reduce their economic expectations or invite a different Player.

4.5 Chapter 4 conclusions and perspectives

This chapter proposed a supplementary solution approach to the Stochastic Collaborative Joint Replenishment Problem (S-CJRP), augmented by means of Discrete-Event Simulation (DES). The DES augmented S-CJRP allows to analyze more complex scenarios, closer to reality, which included variations in additional parameters not viable in the original heuristic approach proposed in Otero-Palencia, Amaya-Mier, & Yie-Pinedo (2018). This approach also allowed for addressing three main practical issues: First, how the increase in scale through collaboration outperforms investments in individual capacity expansion. Second, to decide if the supply chain coordination must be insourced or outsourced, and lastly to evaluate how to manage the entry of new players into a previously established coalition.

In general, with the incorporation of variability in the lead times (a stochastic variable in the practice) is verified that S-CJRP is robust in the sense that the surplus persists even under these variations. After addressing the first issue, we verified that the proposed collaborative model (S-CJRP) exhibits potential savings derived from the exploitation of economy of scale, thanks to a better item replenishment coordination. This model could be practical for practitioners aiming to reduce their logistic cost. Nevertheless, it could be particularly convenient for companies with limited warehouse capacities, reduced budget or insufficient demand rate to reach economies of scale, such as the SME's case. The outputs available in Section 4.4.2 demonstrated potential average cost reductions in the range of 26.7% to 30.4% with $n = 10, 15 \text{ and } 20$ family items, for four players with limited warehouse capacities. It is important to note that despite introducing greater stochasticity in the model, it is robust and continues to demonstrate potential savings.

In addition, it was found that partners pre-selection might be a key issue for success in agreement formation. In the tests of Section 4.4.2, we considered both heterogeneous and homogenous coalitions. The firsts are composed both by large players (with high demand and volume) and small players (low demand and volume) while the second are formed by players with similar shares of items and volume of cargo. An insight from the analysis is that savings achieved in the heterogeneous cases are unequal, since small players perceive large increases in scale, so their savings are greater; conversely, large players perceive few savings. The homogeneous cases show similar savings; players with comparable cargo volume and demand receive comparable savings. Apparently forming coalitions between comparable players is fairer facilitating the agreements formation. However, under our approach the decision to form or not a coalition always depends on the players' returns expectation.

The proposed logistic strategy provides concrete and cost-effective means towards oftentimes elusive collaboration by translating certain collaboration benefits into individual member's payoffs. I.e., players can share a cheaper warehouse facility with a smaller capacity than the sum of their individual optimal capacities, thanks to the efficient replenishment coordination. Additionally, the cost of this capacity expansion is less than what each player would have to afford individually, since the S-CJRP' Shapley function enables the players to share overall costs and surplus according to their expected marginal contributions. Moreover, players with strong capacity limitations, which prevent them to reduce their management inventory costs, are now able not only to overcome these limitations, but also to reduce their cost beyond the individual optimum cost, as is show in Section 4.4.1. In practical settings, a higher and unified volume could let players to bargain even better prices with 3PL providers.

In other hand, one of the useful properties of the S-CRJP's cost function is its insensibility over T (the cycle period decision) in the optimal point's proximity due to the flat shape of the cost curve, a heritage from Harris (1913) EOQ inventory models. This property allows reducing even more the warehouse size without significant investment increment.

Practitioners should consider this property before deciding the warehouse size, since in some cases could be economically convenient the use of a shared capacity.

Regarding the external or internal nature of the coordination role, it was shown that the lack of coordination results in extra costs due to additional replenishments (Section 4.4.3). Regardless of which player skips a scheduled replenishment, thus incurring in an additional individual dispatch to compensate, the total coalition logistical cost is increased in an amount equal to the mayor cost (S). In this sense, each player failing the replenishment schedule must face the additional cost and significantly reduce his/her savings. Non-compliances in the replenishment schedule may be due to a lack of control and/or management, so a coordinator of the coalition's joint-order is required. If the coordination is insourced, i.e., in charge of the coalition, it is inevitable to internally assume overruns; but if the coordination is outsourced the overruns responsibilities are external and less likely, given the 3PL superior expertise. The cost of coordination must be less than the savings generated by the collaboration so the model remains profitable and justly charges each player using the Shapley Value method. Although in our analysis we do not consider extra costs for holding unscheduled cargo at the origin, it is possible that the 3PL requires an additional payment. However, this condition depends on the negotiation terms established with the 3PL. Alternatively, 3PL could keep safety stock in the origin to cover for delays, but at an additional cost.

Finally, regarding the third issue on entry management, we concluded that the only viable collaborative scenarios considering the arrival of a new player to a coalition are those in which all the (preceding and arriving) players reduce their cost. A second concern in this regard is determining how much the new player must pay to join the coalition. The recommendation is that the new player must assume the possible costs of capacity expansion, i.e., additional warehouse space, shelves, adequacies, etc. Additionally, the initial players could demand an additional fee for the future savings that the new player would have. An expression was proposed to determine such fee as the player's annual savings among the coalition discount rate. The final decision to join the coalition depends on the economic expectations of the new player and his expected return on the investment.

A continuous operation may reduce operational costs once the learning curve is reached, so that the players could renegotiate rates conveniently with the logistics operators. A continuous efficient operation could attract other potential players aiming for reducing their logistics costs.

This chapter expanded the knowledge about the usefulness of the S-CJRP model, and also provided useful directions for practitioners on how to better exploit the potentialities of the model, how to better manage its coordination, and how to manage the expansion of the number of players in a coalition. In the next chapter, we will present a novel extension of the JRP model. This new version called S-MJRP, in addition to pursuing cost reduction, pursues the reduction of emissions generated during the transport of inventory. This model allows determining what the fleet configuration and efficient inventory policy should be when regulations are imposed on the maximum number of emissions generated or when it is required to have a specific fleet composition.

CHAPTER 5. Inventory and Fleet Purchase Decisions Under a Sustainable Regulatory Environment

This chapter studies the direct impacts of environmental policies on logistics practices. Specifically, the authors estimate the potential changes in inventory and fleet purchase decisions under a set of policies designed to improve the environmental efficiency of transport activities, through a reduction of overall transportation emissions; and requirements for a fleet mix to include zero and near-zero emission vehicle technologies, or, minimum vehicle type shares. The chapter introduces a constrained stochastic multi-objective joint replenishment problem (S-MJRP) to evaluate the policies while considering logistics costs and emissions as objectives. Moreover, the authors developed a solution algorithm and conducted empirical analyses. The results highlight the trade-off between capital investments in zero-emission vehicles and the logistics costs required to abide by the requirements of the mentioned regulatory policies. The results provide insights for both private and public stakeholders as they consider the logistics challenges and opportunities generated by these sustainability policies.

The related contributions of this chapter are:

***** The introduction of the constrained stochastic multi-objective joint replenishment problem (S-MJRP), a novel JRP extension. The S-MJRP determines the efficient replenishment frequency and shipment size for multiple commodities with finite warehouse capacity, multiple transportation unit capacities and features, stochastic demand, non-zero lead-times and considering logistics costs and emissions as objectives.

***** The improvement in understanding of the direct economic impacts of environmental policies on logistics practices, including inventory, replenishment, and fleet purchase decisions, when are imposed sustainability astringent policies. In this case, policies seeking to improve the environmental efficiency of transport activities by reducing overall transportation emissions, and by requiring a fleet mix that includes zero and near-zero emission vehicle technologies.

The current chapter is based on the next publication: Jaller, Miguel; Otero-Palencia, Carlos; Yie-Pinedo (2019).

Taylor & Francis
Taylor & Francis Group

Supply Chain Forum: An International Journal

ISSN: 1625-8312 (Print) 1624-6039 (Online) Journal homepage: https://www.tandfonline.com/loi/tscf20

Inventory and fleet purchase decisions under a sustainable regulatory environment

Miguel Jaller, Carlos Otero-Palencia & Ruben Yie-Pinedo

To cite this article: Miguel Jaller, Carlos Otero-Palencia & Ruben Yie-Pinedo (2019): Inventory and fleet purchase decisions under a sustainable regulatory environment, Supply Chain Forum: An International Journal, DOI: 10.1080/16258312.2019.1664257

To link to this article: https://doi.org/10.1080/16258312.2019.1664257

Published online: 22 Sep 2019.

Published September 22, 2019

5.1 Introduction

In the previous chapter closed the discussion about the S-CJRP model, its advantages, and directions on how to implement it in a better way. In this chapter, a new version of the JRP model is introduced, which does not include a collaborative strategy per se, but it turns out to be useful because it allows to determine inventory and fleet configuration policies that comply with sustainability policies imposed by the authorities.

Greater efficiency of freight transportation and logistics activities is critical for a sustainable transportation system. The vehicles required to move the cargoes needed to supply the rapidly increasing demand in urban areas, with a projected 66% urbanization rate by 2050 (Department of Economic and Social Affairs, 2014), will generate a number of disproportional negative externalities (Jaller & Harvey, 2018; Jaller, Sánchez, Green, & Fandiño, 2016). These externalities include social, environmental, and economic impacts, mostly related to traffic congestion, noise, greenhouse gas (GHG) and criteria pollutant emissions, and safety. The increase of air pollutant concentrations from vehicle emissions have a direct impact on human health, increasing disease burdens and environmental damages (Forkenbrock, 1999).Some studies suggest that environmental emissions will increase by approximately 30% compared to 1990 levels , with expected significant consequences for the climate and the lives of U.S. citizens (U.S. Department of Energy & Office of Scientific and Technical Information, 2013).

Throughout the world, countries and organizations are investing effort in mitigating the impacts of human activity. For example, the World Bank and other organizations just committed $47 billion to climate adaptation in Africa (World Bank, 2019). In the U.S., the state of California has a long tradition of developing mitigation and abatement measures. A large and economically important state with some of the largest ports and metropolitan areas in the country, California's industrial and agricultural activity, geographical characteristics, as well as its position as an international trade gateway have resulted in major environmental issues. For instance, California has a few of the top non-attainment air basins in the country, and there is a close relationship between these areas and the flows of freight traffic (Jaller, Pineda, & Ambrose, 2018; Jaller et al., 2016).

To contend with these issues, transportation and environmental agencies have developed several guidelines, plans, and regulations. These include fuel taxes to discourage combustion engine vehicles, purchase voucher incentives for cleaner vehicles, stringent fuel efficiency standards, vehicle manufacturer mandates, control and measurement systems, and others measures. In 2016, a multi-agency effort released the California Sustainable Freight Action Plan (CSFAP) (California Governor's Office, 2016) based on three main objectives, to: improve freight environmental efficiency (the relationship between emissions and economic output); foster the use of zero and near-zero emission vehicles; and improve economic competitiveness. The plan includes some actions to improve efficiency based on the use of cleaner vehicles and technologies, though it lacks details about the types of operational improvements that would be required, and the potential economic consequences of such actions. If effective, these policies and initiatives will generate much needed benefits towards greater sustainability. However, the immediate impacts to businesses and fleets are not necessarily understood, and these are important to achieve CSAFP's third objective, to improve economic competitiveness (Jaller et al., 2018)

To fill this gap, this chapter evaluates the direct economic impacts of environmental policies on logistics practices, including inventory, replenishment and fleet purchase decisions. This work considers policies seeking to improve the environmental efficiency of transport activities by reducing overall transportation emissions, and by requiring a fleet mix that includes zero and near-zero emission vehicle technologies. To fully consider the operational and economic ramifications of these policies, the authors developed a constrained stochastic multi-objective joint replenishment problem (S-MJRP). The S-MJRP, and extension of the joint replenishment problem, determines the optimal replenishment frequency and shipment size for multiple commodities with warehouse and transportation (number of vehicles) capacities considering logistics costs and emissions as objectives. The authors conduct empirical analyses to determine the trade-off between these decisions, and the resulting costs and emissions of complying with these policies.

The document is organized as follows: Section 5.2 provides a general background on the implications of environmental policies on logistics activities, defining the policies considered in this work and the assessment methodology. Section 5.3 introduces the mathematical model and the assumptions for the S-MJRP. Section 5.4 briefly describes the solution approach while Section 5.5 discusses the empirical results. The chapter ends with conclusions in Section 5.6.

5.2 Background

Freight transport in general, and freight flows in particular, are the result of economic and logistics decisions. On one hand, the amount of cargo that needs to be transported is the physical manifestation of the economic activity, i.e., transactions between economic players on both sides of the production and consumption process. The type(s) of vehicles and modes used to transport the cargo, the shipment sizes and frequencies are the result of logistics decisions. Using the traditional inventory economic order quantity (EOQ) model (Harris, 1915), Holguín-Veras et al. (2011) show the relationship between the amount of cargo and the amount of freight transport activity. An increase in commodity flows does not necessarily generate a proportional increase in freight traffic because of changes in shipment size, replenishment frequency, and vehicle(s) used. Consequently, the amount of environmental impacts from freight transportation results from both consumption levels and the associated vehicle flows used to transport the goods. Mitigating environmental impacts by limiting consumption levels will directly affect the economy, therefore, measures are required to improve the efficiency of vehicle flows, including the vehicles and other equipment, and the operations involved.

5.3 Environmental Policies

Diesel vehicles transport the largest share of commodities, generating significant GHGs and criteria pollutant emissions. Recently, the California Air Resources Board (CARB), to support the CSFAP and to align with other regulations,[5] initiated discussions and work on the Advanced Clean Truck (ACT) Program. ACT's goal is "…to achieve NOx and GHG emission

[5] Sustainable Communities and Climate Protection Act of 2008–SB 375; California Global Warming Solutions Act of 2006–AB 32; Community Air Protection Program–AB 671; California Environmental Quality Act - SB-617; and Clean Energy & Pollution Reduction Act–SB 350.

reductions through advanced clean technology, and to increase the penetration of the first wave of zero-emission heavy-duty technology." (California Air Resource Board, 2018) As part of ACT, CARB is considering requiring companies and fleets to acquire zero and near-zero emission vehicles. Moreover, Senate Bill 44 "Medium-duty and Heavy-duty Vehicles: Comprehensive Strategy," and Assembly Bill 1411 "Integrated Action Plan for Sustainable Freight" introduce targets for vehicle emission reductions and the deployment of 200,000 zero-emission vehicles and equipment by 2030.

While these policies and plans have specific environmental objectives, it is not clear what their short-term economic impacts will be for the businesses and fleets they target. This work will evaluate some of those impacts, focusing on two specific policies or measures that encompass the main instruments from the reviewed policies and bill proposals:

Policy 1: Improving Environmental Efficiency: Emission Reductions

Consistent with the objectives of the CSFAP and other policies, a key goal is to try to reduce the emissions from transportation activity. This work assumes that a policy will set annual percentage target reductions from a base level. The base level is assumed to be the private cost-efficient operation of a business or fleet.

Policy 2: Fostering Zero and Near-Zero Emission Vehicles: Fleet Mix Requirements

This instrument considers that to foster the reduction of environmental emissions, cleaner technologies need to be fostered, and business and fleets will be required to have a minimum percentage of zero and near-zero emission (ZEVs) technologies in their fleets. This is in line with on-going discussions as part of ARB's ACT Program.

5.3.1 JRP: A Multi Product Inventory Model

For years, the primary objective of logistics management has been to effectively and efficiently replenish inventory, satisfying the customer's desired service level at the minimum cost. Despite the fact that companies have been able to achieve high levels of logistics sophistication and efficiency, there has been a high cost for the system overall, and the environment, in terms of negative externalities (Jaller et al., 2016). In general, inventory decisions (e.g., stock levels, replenishment, shipment sizes, frequencies) affect other aspects related to transportation outcomes, facility location, and asset utilization. A traditional and widely used inventory management model is the JRP. As mentioned in the previous chapters, the JRP has been recognized for its potential for real-world applications, and many of them are illustrated in Chapter 3. This chapter builds on some of those previous works and proposes a novel *Stochastic Multi-Objective Joint Replenishment Problem* (S-MJRP). The S-MJRP assumes stationary normally distributed demand with fixed service level and several constraints. It considers finite transportation (for different types of vehicle technologies and capacities) and warehouse capacity, as well as budgetary constraints. Moreover, the model considers total logistics costs (ordering, inventory, transportation) as the first objective, and transportation-related emissions as the additional objective. Specifically, the proposed model contributes by combining different types of vehicles (powertrain and fuel technologies) and capacities, stochastic demands, and multiple objectives to expand the literature and applications of the JRP.

5.3.2 Impacts of Sustainability Policies on Logistics Decisions

Logistics decisions are broadly based, with factors such as inventory management and fleet procurement key to determining the amount of transport activity needed to serve a specific demand. In most cases, inventory management depends on trade-offs between ordering, holding, and transport costs. The policies considered in this work will have direct implications on transportation costs (different vehicle technologies represent different total costs of ownership) (Jaller et al., 2018), thus impacting inventory practices. The implementation of sustainable policies such as those analyzed here will also have a direct effect on logistic costs due to the need to replace regular vehicles with zero-emissions or near zero-emissions vehicles.

In addition to the necessary investments required to incorporate zero emissions vehicles into fleets, the technical characteristics of these vehicles will impact the logistics. For instance, battery electric vehicles (BEVs) have a reduced load capacity (or range) due to the battery pack's weight, thus transporting a determined amount of cargo may require either a larger number of vehicles or making a greater number of trips. This will in turn not only raise operating costs, but also make the management of the fleet more complex, with more maintenance processes, insurance, physical space, and the need to hire additional drivers. Likewise, at the operational level, it is necessary to decide on the frequency in which the replenishment should be done, the batch size and the storage decisions. These decisions are affected by the available working capital (which could potentially be reduced by capital expenditures) and the available storage space. At the tactical level, companies must then decide whether to design their supply chains to pull or push, sacrifice service levels to reduce storage costs or exploit demand more aggressively (Ballou, 2007). Additionally, any decision to expand the company could be affected by emission level mandates, since any expansion in the operation implies a greater number of physical movements and therefore more externalities. Ultimately, sustainable policies have significant and broad ranging impacts on the operative and tactical decisions of companies.

Accordingly, the M-SJRP model allows a better understanding of the potential impacts on costs and logistic decisions at the operational and tactical levels of the two sustainable policies analyzed in this study. Specifically, the model quantifies the trade-offs between the logistic costs associated with the replenishment of inventory and the emissions generated when these policies are implemented.

5.4 The M-SJRP Model

The proposed Stochastic Multi-Objective Joint Replenishment Problem (S-MJRP) model determines a cost-efficient replenishment frequency and shipment size for multiple commodities, and the number and type of vehicles required to transport the cargoes. The model considers warehouse and transportation (dependent on the number of vehicles available/acquired) capacities, and budgetary constraints to minimize logistics costs and emissions.

The main assumptions are:

1. *The replenishment lead time is fixed*
2. *Integrated supplier-retailer operations, and direct shipments from a single warehouse to a single retail location*
3. *Stationary and normally distributed demand*
4. *Limited warehouse capacity*
5. *Limited operational capital expenditures budget*
6. *Multiple types of vehicles with various capacities*
7. *Compatible and non-perishable commodities*
8. *Demand shortages are not allowed.*

The model notation is as follows:

Sets

I $Set\ of\ commodity\ family\ i = 1, 2, 3, \dots, n$
J $Set\ of\ all\ vehicles\ \ j = 1,2,3, \dots, g.$
M $Set\ of\ shipments\ \ m = 1,2,3, \dots,.$
n: $Number\ of\ family\ items$
g: $Number\ of\ vehicles$

Decisions Variables

$\mathbf{T}$: $Reference\ time\ between\ two\ consecutive\ replenishments$
$\mathbf{k_i}$: $Positive\ integer\ multiplier\ of\ T\ for\ the\ item\ i;\ i \in I$
$\boldsymbol{F_{jm}}$: $Fleet\ percentage\ of\ vehicle\ type\ j\ used\ in\ shipment\ m$
$\boldsymbol{x_j}$: $Number\ of\ vehicles\ type\ j; j \in J$

Parameters

D_i: $Annual\ demand\ of\ commodity\ i;\ i \in I$
S: $Major\ ordering\ cost\ for\ commodity\ i;\ i \in I$
s_i: $Minor\ ordering\ cost\ for\ commodity\ i;\ i \in I$
$Z_{\alpha i}$: $Safety\ inventory\ level\ for\ commodity\ i;\ i \in I$
σ_i: $Standard\ deviation\ of\ demand\ for\ i;\ i \in I$
h_i: $Inventory\ cost\ for\ commodity\ i;\ i \in I$
a_j: $Operating\ cost\ of\ vehicle\ j; j \in J$
A_j: $Purchase\ cost\ of\ vehicle\ j; j \in J$
E: $Reference\ Emission\ Level$
v: $Subset\ of\ zero\ or\ near - zero\ emission\ vehicles\ from\ j$
e_j: $Emission\ rate\ of\ vehicle\ j; j \in J$

c: $Cycle\ time\ between\ the\ warehouse\ and\ retailer$
w_i: $Weight/volume\ per\ unit\ of\ commodity\ i;\ i \in I$
W_j: $Capacity\ of vehicle\ \ j;\ j \in J$
K: $Maximum\ storage\ capacity\ available$
B: $Maximun\ budget\ for\ vehicle\ investment$
L_i: $Lead\ time\ \ for\ commodity\ \ i;\ i \in I$
r: $Daily\ working\ hours$
H: $Least\ common\ multiple\ of\ set\ \ k_i$
ε: $Percentage\ reduction\ in\ emissions$
γ^v: $Percentage\ of\ zero\ and\ near - zero\ emission\ vehicles, v, in\ the\ fleet$

The general model formulation is:

$$Minimize:\ TC\left(T, k_i, x_j, F_{jm}\right)$$
$$= \left(S + \sum_{i \in I} \frac{s_i}{k_i}\right)/T + \left(\frac{T}{2}\sum_{i \in I} D_i k_i h_i + \sum_{i \in I} Z_{\alpha i}\sigma_i h_i(\sqrt{L_i + Tk_i})\right) \quad (5\text{-}1)$$
$$+ \left(\frac{\left(365\frac{r}{c}T\sum_{m\in\{1-H\}}\sum_{j\in J}F_{jm}x_j a_j\right)}{TH} + \sum_{j \in J} A_j x_j\right)$$

$$Minimize:\ EI\left(T, k_i, x_j, F_{jm}\right) \quad (5\text{-}2)$$
$$= \sum_{m\in\{1-H\}} 365\frac{r}{c}T\sum_{j\in J}F_{jm}x_j e_j \Big/ TH$$

$Subject\ to$:

$$\sum_{i \in I} D_i w_i T k_i + \sum_{i \in I} Z_{\alpha i}\sigma_i w_i(\sqrt{L_i + Tk_i}) \le K \quad (5\text{-}3)$$

$$\left(\sum_{j \in J} A_j x_j\right) \le B \quad (5\text{-}4)$$

$$\sum_{i\in I}\left((1 - min\,[1,\ m - (\lfloor m/k_i \rfloor k_i)]) * (D_i T k_i w_i)\right) \le 365\frac{r}{c}T\sum_{j\in J}F_{jm}x_j W_j \quad \forall m \in \{1 \dots H\} \quad (5\text{-}5)$$
$$0 < T < 1;\ 0 \le F_{jm} \le 1;\ \ k_i, x_i{:}\, integer$$

The *first* objective, or *minimization of logistics costs* (TC) in (5-1) considers the costs of ordering, inventory, transportation and fleet procurement. The first term refers to the annual ordering cost, and has two components: $\frac{S}{T}$ is the annual ordering cost (independent of the number and type of commodities); and the second: $\sum_{i\in I}\frac{s_i}{Tk_i}$ is the annual ordering cost dependent on the shipment composition (type of commodities). Note that S is independent of the number of commodities in an order. Such cost aggregates the fixed cost per order due to document processing, costs of preparing and receiving orders, and materials management. S is assumed equal for all orders and commodities. Conversely, s_i takes place only when commodity i is included in an order. This minor ordering costs refers to the costs of handling, packing and any additional efforts to aggregate/disaggregate cargo.

The second main term considers the effect of the stochastic demand assuming that demand is approximately normally distributed. Without loss of generality, the demand might represent the aggregated demand from many customers. Moreover, the work assumes that customers' demands are independent and identically distributed random variables.

Consequently, the Central Limit Theorem justifies the assumption that total demand is approximately normally distributed (Porteus, 1990). Accordingly, let σ denote the standard deviation, let P_N denote the unit normal distribution function, and let z satisfy $P_N(z) = \alpha$. That is, $z = {P_N}^{-1}(\alpha)$. The expected stock level is given as $X = D + z\sigma$, where D is the average annual demand. In this case, the first component of the second term: $\frac{T}{2}\sum_{i\in I} D_i k_i h_i$ includes the average annual average holding cost of the inventory cycle, while the second: $\sum_{i\in I} Z_{\alpha i}\sigma_i h_i(\sqrt{L_i + Tk_i})$ includes the cost of holding the safety stock, which allows for a cushioning against demand fluctuations warranting an expected service level of (α)100 %.

Finally, the third term includes the annual transportation cost $\left(\frac{\left(365\frac{r}{c}T\sum_{m\in\{1-H\}}\sum_{j\in J}F_{jm}x_j a_j\right)}{TH}\right)$ and the fleet procurement costs $(\sum_{j\in J} A_j x_j)$. H is the least common multiple of the set k_i , and represents the relative cycle time for a joint replenishment of all commodities; $365\frac{r}{c}T$ is the maximum number of trips that a vehicle can complete per replenishment cycle T assuming that all vehicles can travel at a comparable speed; and the expression: $\sum_{m\in\{1-H\}}\sum_{j\in J}F_{jm}x_j a_j$ estimates the operational cost for the vehicles type j used for shipment m during the cycle H. Each cycle H is repeated every $\frac{1}{TH}$ times.

The *second* objective, or *minimization of transportation emissions* (EI) in (5-2) quantifies the amount of emissions generated by the vehicles transporting the various shipments over the whole inventory planning horizon, one year in this case.

The first constraint, or *warehouse capacity* (5-3) guarantees that in the worst case (when all commodities are replenished together) the total replenishment volume: $\sum_{i\in I} D_i w_i T k_i$ plus the security stock volume: $\sum_{i\in I} Z_{\alpha i}\sigma_i w_i(\sqrt{L_i + Tk_i})$ do not exceeds the maximum storage capacity. The *budget capacity* constraint (4) warrants that the expenditures in vehicles $(\sum_{j\in J} A_j x_j)$ do not to exceed the capital budget B. Finally, the *transportation capacity* constraint (5) controls that there are enough vehicles to transport the cargo for each replenishment. The expression $365\frac{r}{c}T\sum_{j\in J}F_{jm}x_j W_j$ indicates the percentage of the vehicles type j used to transport the shipment size $\sum_{i\in I}\left((1 - min\,[1,\, m - (\lfloor m/k_i \rfloor k_i)]) * (D_i T k_i w_i)\right)$ in the shipment m.

5.4.1 Implementation of Environmental Policies

First policy: Reducing fleet emissions

One of the goals of the California Air Resources Board (CARB) is to reduce the amount of emissions that companies generate from their transportation operations to improve environmental efficiency. The model assumes a base emission level E , and an expected percent reduction ε. To model this policy, the authors developed constraint (6). The numerator $(\sum_{m\in\{1-H\}} 365\frac{r}{c}T\sum_{j\in J}F_{jm}x_j e_j)$ in (6) counts all of the trips done using the vehicles type j during H (least common multiple of set) considering the maximum amount of trips that can be done per day: $\frac{r}{c}$. The model then multiplies all trips in the cycle by the vehicle emissions rate e_j, and by the total number of cycles per year $\left(\frac{1}{TH}\right)$ to estimate the annual amount of emissions.

Consequently, the model for the first policy results from aggregating expressions (5-1 to 5-5) and (5-6).

$$\frac{\sum_{m\in\{1-H\}} 365\frac{r}{c}T\sum_{j\in J} F_{jm}x_j e_j}{TH} \leq \varepsilon E \tag{5-6}$$

Second policy: Requiring zero and near-zero emission vehicles in the fleet composition

The second policy also corresponds to CARB's strategy to reduce emissions. In this case, the policy will require companies to keep a minimum percentage of zero and near-zero emission vehicles v in their fleets, γ^v. Accordingly, the authors developed constraint (7). The numerator $\left(\sum_{j\in J^v} x_j\right)$ in (7) counts the number of near-zero or zero-emissions vehicles in the fleet. While the denominator $\left(\sum_{j\in J} x_j\right)$ is the fleet size.

$$\frac{\sum_{j\in J^v} x_j}{\sum_{j\in J} x_j} \geq \gamma^v, \qquad \forall\, v \tag{5-7}$$

The model for the second policy results from aggregating expressions (5-1 to 5-5) and (5-7).

5.5 Solution Approach

In this work, the M-SJRP is solved using a random evolutionary three-level meta-heuristic (MH3) guided by the exponential number of feasible solutions and the non-linear non-continuous nature of the model. The M-SJRP is an NP-hard problem, as is its base problem, the JRP. Specifically, the complexity of the JRP is given by the constraints of the model, so it will remain NP-hard even if the objective function includes new, or reduced elements. The stochastic portion of M-SJRP is solved first to find scalar values as an input for our model.

In each level, the MH3 deals with a fraction of the solution and controls the feasibility of the generated solutions. The problem was decomposed in two sub problems: the first problem (P1) finds good solutions for T and $K's$; the second problem (P2) finds good solution for $X's$ for a given $(T, K's)$ combination.

Overall, the MH3 is a combination of a genetic algorithm (GA) and a decomposition algorithm. The rationale is to solve the problem with a two-level algorithm and finally to apply another algorithm to improve the solution. Figure 5-1 shows a schematic of the solution approach, Step 1 generates a random population of $(T, K's)$ tuples, been T the reference time between two consecutive replenishments, and $K's$ a vector with the k_i (relative frequency of replenishment) for each product.

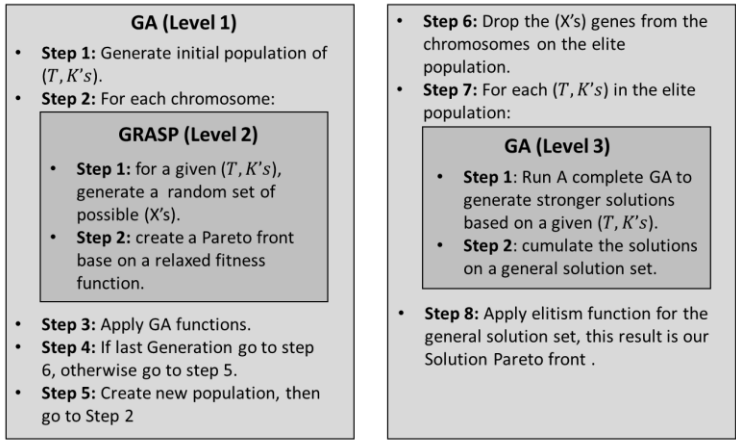

Figure 5-1: Proposed M-SJRP solution procedure MH3

For each solution on the population, MH3 solves P2, and because P2 is a multi-objective problem, the solution of each P2 is a Pareto frontier. MH3 solves P2 using a greedy randomized adaptive search procedure (GRASP) algorithm that randomly creates a large population of possible $X's$, and then applies hard dominance rules to choose the best ones. Figure 5-2 represents this process. At the end of each iteration, each tuple $(T, K's)$ will have a Pareto frontier of $(X's)$. The algorithm generates an improved population with each of the Pareto points.

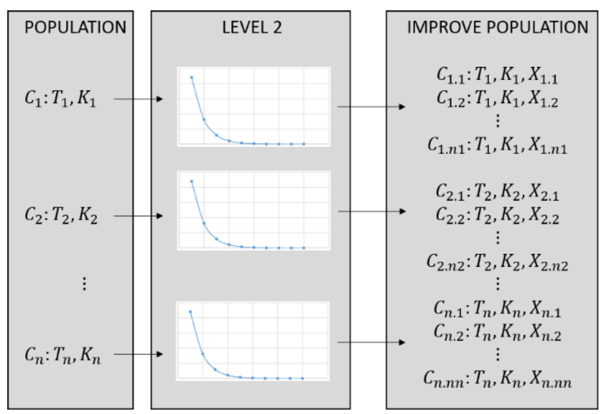

Figure 5-2: General schema of the Second problem (P2) procedure at level 2

The next step applies GA functions to the improved population, swapping the $K's$ vector (K-gene) of two solutions, or the $X's$ vector (X-gene). Then, it applies hard dominance to the population and creates a new population for the next generation. This population will contain the crossover sons, the mutation sons, the elite population, as well as, new chromosomes and random chromosomes taken from the improved population (not elite). Finally, the algorithm drops all the X-genes and a new iteration begins.

Once all iterations are complete, the algorithm uses the final elite population, drops all the X-genes, eliminates duplicates, and applies the last level (level 3) of the algorithm. This algorithm is also a GA algorithm, which solves P2 more robustly than the level 2-GRASP. For each tuple of $(T, K's)$, the algorithm generates a population of X-genes and applies GA elite, GA mutation, and GA crossover functions over this population. This procedure repeats over several generations. As shown in Figure 5-3, each solution of the elite population will contain a Pareto frontier, and again, the model creates a new Pareto after applying strong dominance functions.

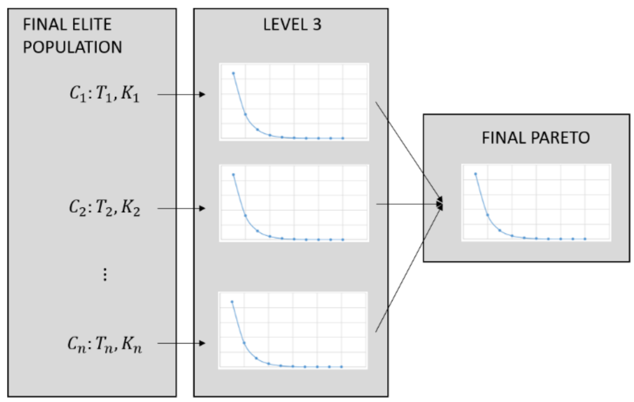

Figure 5-3: General schema of the Second problem (P2) procedure at level 3

5.6 Empirical Analyses

The analyses concentrate on an integrated suppliers-retailer operation, considering a single warehouse that supplies a single retail location. Moreover, although the mathematical model could be expanded to consider any pollutant, the empirical analyses focus on CO_2 emissions. In this section, we consider the two policies introduced in Section 5.3.: *reducing fleet emissions* and *requiring zero and near-zero emission vehicles in the fleet composition*. In the considered scenario, the retailer mainly trades ten different commodity families, supplied by a warehouse 50 miles away. A commodity family could be comprised of several products with similar features, such as personal hygiene products. This approach is useful in practical settings because there could be many commodities with no significant demand or complementary commodities. Second, in computational terms, it could be restrictive to run the model with too many commodities. Usually, up to 5 families or categories of products are used in the literature to demonstrate and analyze the methodologies in a reasonable timeframe (Khouja & Goyal, 2008). The empirical data is based on actual parameters observed in logistics practice. Accordingly, the average major ordering cost (S) is \$ 4,000 per joint order. The business expects to maintain a service level $(z_{\alpha i} = 1.64)$ of 95% in all products, with an average lead time equal to 11 days (0.03 years). Vehicles operate 8 hours per day, and the delivery round trip from warehouse to retailer is 4 hours. Table 5-1 summarizes additional information about the demand characteristics and costs.

Table 5-1: Item parameters for analytical example

Parameter	1	2	3	4	5	6	7	8	9	10
Annual demand (D_i)	700,000	500,000	400,000	55,000	40,000	600,000	450,000	500	450	400
Minor cost $/shipment ($s_i$)	90	100	135	400	475	80	130	1000	1000	1500
Holding cost $/unit ($h_i$)	10	12	12	12	12	10	10	15	15	15
Unit weight mts3 (w_i)	0.25	0.75	0.5	2	4	0.25	0.75	4	4	4
$Z_{\alpha i}$	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64
Standard deviation (σ_i)	35,000	65,000	25,000	4,000	4,500	65,000	70,000	50	60	20
Lead time yrs./shipment (L_i)	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03

The analyses consider diesel, diesel/electric (hybrid) and battery electric vehicles (BEVs) as vehicle/fuel options (See Table 5-2 for a summary of vehicle parameters). Additionally, the scenario considers access to for-hire diesel trucks at an average price of $ 10 per mile.

The analyses consider zero tailpipe emissions for BEVs, though the weight of the battery reduces the payload capacity. The authors estimated the parameters using commercial and technical information provided by different manufacturers, such as Daimler, Tesla, Nikola Motors, as well as other publicly available information (Jaller et al., 2018). The analyses assume a vehicle linear depreciation over a 10-year period.

Table 5-2: Fleet parameters for analytical example

	Diesel	***Rented***	***Hybrid***	***EV***
Operational cost $/shipment ($a_i$)	0.71	10	0.63	0.44
Purchase cost $/vehicle ($A_i$)	160,000	0	250,000	290,000
Vehicle cap. mts3/unit (W_i)	75	75	63.75	52.5
Emissions grs/shipment (e_i)	1667.32	1667.32	1167.12	0

Offering a comprehensive view of the results, Figure 5-4 shows the whole Pareto frontier, then in Section 5.6.1. and Section 5.6.2. we apply the restrictions of the first and second policy respectively, which is analogous to eliminating some Pareto solutions.

5.6.1 Evaluating the First Environmental Policy

Figure 5-4 shows the resulting Pareto frontier (optimal points considering both objectives) for any value of E and ε, which allows an estimation of the trade-offs between the various costs and emissions. The horizontal axis in Figure 4 represents the first objective: cost, in USD (in 100,000s). The vertical left axis represents the second objective: emissions, generated in millions (M) of grams of CO_2. The right vertical axis represents the corresponding percentage of the vertical left axis. For instance, 0 grams corresponds to 0%, 24M of grams are almost 70%, and 34.08M of grams are 100%. Therefore, the solution marked as A (top left) represents the cheapest alternative; closest to origin in the Cartesian plane, with a cost of $ 21,698,367, and the largest amount of emissions, 34.08M of grams of CO_2. Similarly, Solution D represents the most expensive solution, but with zero-emissions (tailpipe).

Using the constraint (equation 6) of the first policy, an emissions reduction of 10% or 0.3408M of grams of CO_2 (E = 34.08M and $\varepsilon = 0.1$) is analogous to discarding the two solutions on top, with all solutions below Solution B becoming feasible solutions. Similarly, a reduction of 60% or 20.44 M of grams of CO_2 (E = 34.08M and $\varepsilon = 0.6$) is analogous to discarding all solutions over Solution C, and considering only Solution C and below as feasible.

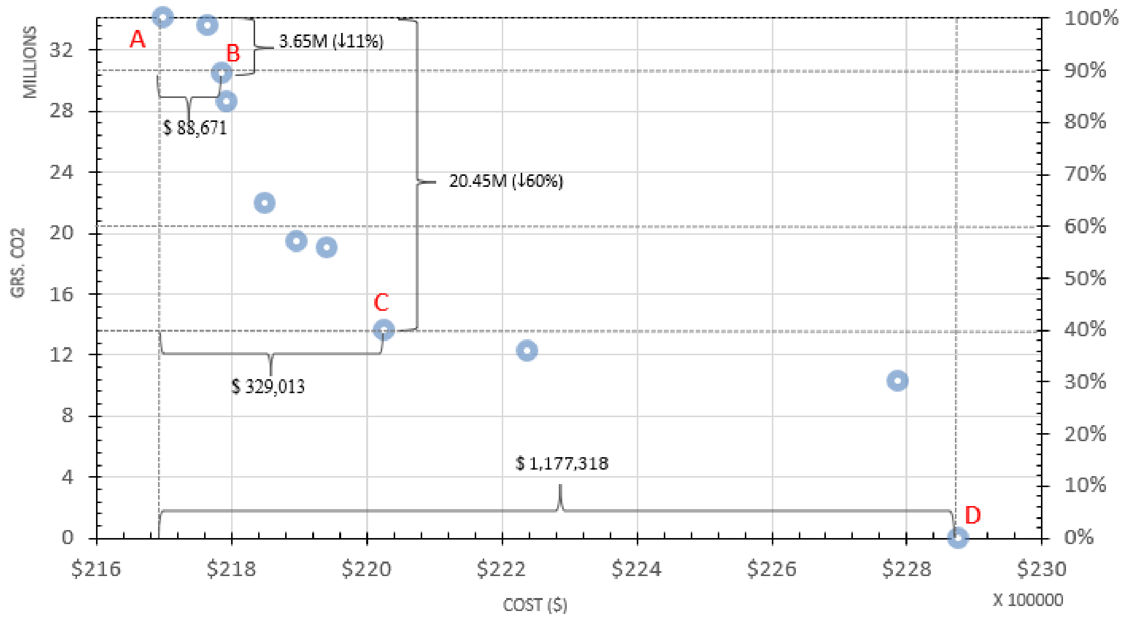

Figure 5-4: Pareto Frontier for First Policy Evaluation

Table 5-3 shows the results of the fleet mix for each solution. Under each vehicle technology, the left side shows the number of vehicles required, while the right side shows the average use (percentage) over the year. The results show that for most of the solutions, the average use is high and homogeneous.

Table 5-3: Number of vehicles and average use for optimal solutions

Solution	Diesel		For-Hire		Hybrid		EV	
1 (A)	-	-	14	1.00	-	-	-	-
2	3	1.0	8	1.00	4	1.00	-	-
3 (B)	1	1.0	8	1.00	5	1.00	1	1.00
4	3	1.0	8	0.92	2	1.00	3	1.00
5	7	1.0	2	1.00	-	-	7	1.00
6	8	1.0	-	-	-	-	9	1.00
7	2	1.0	3	1.00	4	1.00	9	1.00
8 (C)	-	-	-	-	8	1.00	11	1.00
9	-	-	-	-	6	0.65	20	0.79
10	-	-	-	-	8	0.75	13	1.00
11 (D)	-	-	-	-	0	-	23	0.88

Each Colum: Number / Use rate

Table 5-4 shows the estimated results for k_i, T and the cycle H. There are only two different inventory policies (Solutions 1-9, and 10-11). These solutions indicate that joint replenishments happen every sixth and third shipment, respectively.

Table 5-4: Results for ki, T, and H

Solution	$k_i =$ 1	2	3	4	5	6	7	8	9	10	T	H
1 (A)	1	1	1	1	1	1	1	3	2	3	0.1	6
2	1	1	1	1	1	1	1	3	2	3	0.1	6
3 (B)	1	1	1	1	1	1	1	3	2	3	0.1	6
4	1	1	1	1	1	1	1	3	2	3	0.1	6
5	1	1	1	1	1	1	1	3	2	3	0.1	6
6	1	1	1	1	1	1	1	3	2	3	0.1	6
7	1	1	1	1	1	1	1	3	2	3	0.1	6
8 (C)	1	1	1	1	1	1	1	3	2	3	0.1	6
9	1	1	1	1	1	1	1	3	2	3	0.1	6
10	1	1	1	3	1	1	1	1	3	3	0.1	3
11 (D)	1	1	1	3	1	1	1	1	3	3	0.1	3

For instance, Solution 1 or A implies that a replenishment happens every 36.5 days of commodities (families) 1, 2, 3, 4, 5, 6, and 7 (k_i=1). The replenishment of commodities 8 and 10 is every 109.5 days ($3 * 36.5$ days, k_i=3.), and for 9 every 73 days (k_i=2). Table 5-5 shows the various costs and emission levels. The aforementioned solution generates a cost of $21,698,367 and 34,080,000 grams of CO_2. This solution, involving a replenishment every 36.5 days with a supplier 50 miles away, results from the combination of all the associated costs, and the capacity constraints. However, the retailer must hold enough inventory to absorb the demand (with a service level of 95%) and demand fluctuations during the lead time, 11 days in this example. Although probably the retailer would like to partner with another supplier with shorter lead time, then reduce holding costs, there are some reasons why usually retailers prefer to keep partnerships with old' known suppliers: reliability, quality, customer preferences, etc. Moreover, although the algorithm does not warrant the optimal solution, it provides good solutions that balance between ordering cost, holding cost, and transportation. In this instance, the provided solution is the best found (as the solution in Figure 4). If the lead times were shorter and the ordering and transportation costs were relatively low in comparison with the holding cost, the model would probably give a cost-effective solution with a low inventory level but with a larger amount of frequent small orders.

The costs (in Table 5-5) for the different Pareto solutions in Figure 5-4 (ordered in descending order of emissions) provide insights about the potential effect of the first policy. For example, assuming that retailers are cost-driven they will use diesel trucks only, generating the largest emission levels (Solution 1, which corresponds to hiring 14 diesel vehicles). This is point A in Figure 5-4, generating 34.08M grams of CO_2. A policy requiring 10% emission reductions will require the retailer to move along the Pareto to Solution B (reducing 3.65M annual grams of CO_2). This would result in annual costs of $21,787,038, increasing cost by $88,671, keeping constant the inventory cost, and increasing annual transportation costs by 43.3%. Logistics decisions from strategy B require purchasing 7 trucks (1 diesel, 5 hybrid, and 1 EV), and hiring 8.

Table 5-5: Costs and emissions for the different solutions

Solution	Inventory Cost	Operational Cost	Fleet annual Investment	Total Cost	Emissions (Grs-Co2)
1 (A)	$ 21,493,967	$ 204,400	$ -	$ 21,698,367	34,080,000
2	$ 21,493,967	$ 123,583	$ 148,000	$ 21,765,550	33,593,143
3 (B)	$ 21,493,967	$ 123,071	$ 170,000	$ 21,787,038	30,428,572
4	$ 21,493,967	$ 113,940	$ 185,000	$ 21,792,907	28,562,286
5	$ 21,493,967	$ 40,953	$ 315,000	$ 21,849,920	21,908,572
6	$ 21,493,967	$ 14,074	$ 389,000	$ 21,897,041	19,474,286
7	$ 21,493,967	$ 55,328	$ 393,000	$ 21,942,295	18,987,429
8 (C)	$ 21,493,967	$ 14,413	$ 519,000	$ 22,027,380	13,632,000
9	$ 21,493,967	$ 14,413	$ 730,000	$ 22,238,380	12,268,800
10	$ 22,195,623	$ 13,861	$ 577,000	$ 22,786,484	10,224,000
11 (D)	$ 22,195,623	$ 13,062	$ 667,000	$ 22,875,685	0

Note: Fleet annual investment only considers annual vehicles' depreciation

Moreover, if the policy requires a 50% emissions reduction, the retailer would have to use a strategy similar to solution C. This strategy reduces annual emissions by 20.45M grams of CO_2 (60% reduction). This solution increases costs by $329,013 (difference between solution 8(C) and 1(A)), keeping constant inventory costs and increasing transportation costs in 62%.

A more aggressive policy requiring a full reduction in emissions, would necessitate the use of a BEV-only fleet (23 vehicles), increasing total annual costs by $ 1,177,318 (difference between solution 11 and 1); with total inventory costs increasing by 3.2% and annual transportation costs increasing by 30%, considering a vehicles depreciation period of 10 years. The use of electric vehicles reduces operating costs by almost 93%, impacting positively transportation costs. However, the company needs to incur in a major investment; $6.67 million, an important issue for the company cash flow.

In this scenario, the relationship of cost and emissions is not linear; in fact, the absolute value of the slope in the right section of the Pareto (after point C in Figure 5-4) is smaller than the left side, increasing the abatement costs for higher percent reduction goals. For example, while reducing emissions by 60% increases costs by $329,013, the remaining 40% results in $848,305 (difference between solution 11(D) and 8(C)) additional costs. The difference between the solutions 11(D) and 1(A) has an associated cost of $ 1,177,318.

5.6.2 Evaluating the Second Environmental Policy

Similarly, to analyze the second policy the authors take advantage of the Pareto frontier in Figure 5-4. In this case, the goal is to analyze the impacts of requiring a minimum percentage of zero emission vehicles in the fleet. If the policy, for instance, requires a minimum of 60% zero-emission vehicles in the fleet, all solutions above Solution C will be discarded. The next solution below Solution C (Solution 9 in Table 5-3) is the first to comply with the constraint (5-7), which requires a fleet comprised of 20 BEVs and 6 Hybrids vehicles (20/26 *100 = 76.9%). To simplify the analysis, Table 5-6 summarizes the results illustrated in Figure 5-4 and Table 5-3.

Table 5-6: comparison between the policies approaches

Solution	% EV in fleet	% Emission reduction	% Incr. transportation cost	% Incr. replenishment cost	Required fleet invest.
1 (A)	0.0%	0.0%	0.00%	0.00%	$ -
2	0.0%	1.0%	32.87%	0.31%	$ 1,480,000
3 (B)	6.7%	11%	43.38%	0.41%	$ 1,700,000
4	18.8%	16%	46.25%	0.44%	$ 1,850,000
5	43.8%	36%	74.15%	0.70%	$ 3,150,000
6	52.9%	43%	97.20%	0.92%	$ 3,890,000
7	50.0%	44%	119.34%	1.12%	$ 3,930,000
8 (C)	57.9%	60%	160.97%	1.52%	$ 5,190,000
9	76.9%	64%	264.19%	2.49%	$ 7,300,000
10	61.9%	70%	189.07%	5.01%	$ 5,770,000
11 (D)	100%	100%	232.71%	5.43%	$ 6,670,000

The values in the second column could represent fleet requirements from constraint (7) when evaluating the second policy. Moreover, a policy (first) requiring emissions reductions of 16% or more, would be equivalent to an 18.8% minimum percentage of ZEVs in the fleet. Similarly, if a 50% reduction is mandated, the business could use any strategy between points C and D. As discussed before, C requires 8 hybrid and 11 BEVs (57.9% ZEV ratio) for a purchase cost of more than $5 million, thus increasing transportation costs by 160.9%, while only slightly increasing inventory costs (1.52%).

Furthermore, the results show that transportation cost increases due to a larger number of BEVs are not equivalent to the same relative changes in emissions. In other words, a policy (second) seeking a higher percentage of ZEVs, for example to 50%, is not equivalent to a 50% emission reduction target in the first policy. For this empirical example, Solution 7 has a fleet composition where 50% of the vehicles are BEVs, which, however, only represents a 44% emissions reduction.

5.7 Chapter 5 conclusions and insights

This chapter analyzes the economic impacts of two environmental policies designed to reduce emissions due to transportation operations when replenishing inventory. The first policy requires companies to reduce emissions by a specific level, while the second policy affects the fleet composition. To analyze these policies, the work introduces a novel extension of the JRP called M-SJRP. To solve the proposed M-SJRP, the authors designed a random evolutionary three-level meta-heuristic (MH3).

The work implements the proposed model to a case study, where a supplier and a retailer located 50 miles away trading with ten families of commodities. As a strategy to reduce emissions, it was considered the possibility of incorporating zero-emission and near zero-emissions vehicles into a fleet of diesel trucks. The results provide important operational implications for freight transportation businesses, as well as planning, and policy implications for freight transportation stakeholders. From the companies' perspective, the M-SJRP is a useful tool to determine both inventory policies and fleet composition in a cost-efficient manner when the level of emissions produced by vehicles is limited by regulations. On the other hand, from the transportation planner's perspective, this model allows a better understanding of the economic impact for companies of these and other proposed policies. The model could therefore help determine the financial needs of companies in complying with these or other potential policies. Planners and policymakers could design more productive programs to support the transition to ZEVs, or to support environmental efficiency improvements. The results clarify the trade-off between capital investments in ZEVs and logistics costs in abiding by the potential requirements.

The empirical analyses show that the ratio of emission reductions is not linear. For example, reducing emissions by 60% represents an increase in the total cost of replenishment of 1.52%, and an increase in transportation costs of 160.97%. However, to reduce the remaining 40% of emissions, the cost of total replenishment increases by 5.43% and that of transportation by 232.71%, evidencing that aggressive policies could represent a big financial challenge for companies. In addition to the cost increase, the restrictions could force companies to change their logistics operations. Complying with such restrictions could require making such tactical decisions as increasing the number of employees to serve a greater number of vehicles, or increasing the number of transportation management activities, such as maintenance, or it could necessitate acquiring more physical space, requiring companies to expand. At the operational level, the change in frequency of replenishment could force a change in the working hours of workers, or it could increase the intensity of operations in the warehouse and with management.

Although the results are particular to the case study reported here, they provide general insights about the potential operational impacts of such policies. Moreover, the work highlights the need to develop tools like the one presented to support decision making.

FINAL CONCLUSIONS, REMARKS, AND FUTURE EXTENSIONS

The JRP is a powerful practical model in a variety of real-world settings, especially when reviewing some of its original assumptions and enriching the method with complementary contributions for capturing additional and more complex real-world specifications.

This manuscript addressed two extended versions of the JRP: the so-called Stochastic Collaborative Joint Replenishment Problem (S-CJRP) (Chapter 3) and the Multi-Objective Stochastic Joint Replenishment Problem (M-SJRP) (Chapter 5). These models consider an important set of realistic assumptions, dealing with normal demand, multiple items and vendors, non-zero lead times, finite warehouse and transport capacity. The S-CJRP demonstrates that multi-company collaboration in the joint replenishment of inventory could potentially reduce the overall inventory cost; around 31% according to the scenarios tested. Even, those savings could be greater if players strategically choose their partner players. Through experimentation, it was proven that the characteristics of the players influence the individual expected savings. Players must form coalitions with players with similar characteristics; cargo volumes, type of cargo, delivery times, maintenance costs, etc., to obtain greater savings. I.e., a coalition formed by players with symmetric features yields symmetric savings, which increase the chances of coalition formation since savings are more likely to be perceived fairer. Furthermore, it was proven that the collaborative strategy implicit in the S-CJRP could be a financially preferred alternative to access economies of scale than investing individually in capacity expansion. I.e. Companies can access more attractive discounts and can expand their logistics resources capabilities at a low cost without the need to invest resources individually, since sharing cost and risks. This is because better replenishment coordination induces a better resource utilization, vehicles, warehouses, and even expensive processes. In general, this strategy could be effective to leverage resources such as fleets, buildings, shelves, and any shared-use resource doing nothing more than exploiting economies of scale through efficient coordination.

On the other hand, the M-SJRP shows the trade-off between inventory costs and transportation emissions involved in a single supplier-retailer replenishment process, additionally considering budgetary constraints and CO_2 emission reductions. Interestingly, the M-SJRP can be used for a balanced purchase of cleaner trucks using the collaborative approach of the S-CJRP. In addition, this work proposed a proven cost structure in around 160 case studies that allows to parameterize both S-CJRP and M-SJRP model, and related extensions. The structure is the product of the study of the processes and the identification of the cost drivers typical in the inventory replenishment process in Colombia, but which could well be adjusted to be used in other latitudes. This structure becomes a contribution that helps to close the gap of the lack of information on how to estimate the parameters of inventory models in the practice.

A particular novelty from the M-SJRP approach is considering objectives beyond the inventory cost reduction. In the JRP-related literature, most of the models and approaches concentrate on finding the optimal replenishment strategy that minimizes monetary costs. Throughout the world, there are several initiatives and policies that seek to minimize the externalities produced by logistics activities. For example, the externalities associated with the transport and storage of items include environmental emissions, use of resources, congestion, and safety issues, among others, all generated by the vehicles transporting the cargoes, and the equipment at logistics facilities. The JRP and its collaborative variants such as the S-CJRP discussed here, also provide benefits towards those goals by promoting the efficient use of resources (warehouse and transport units), providing direct benefits to the participating agents, and indirect benefits to the system. However, there is no explicit goal for the JRP and variants to optimize beyond cost (or other economic measures).

From the companies' perspective, the M-SJRP is a useful tool to determine both inventory policies and fleet composition in a cost-efficient manner when there are goals (voluntary or regulated) of emission reductions, or mandates for cleaner fleet compositions, among other types of sustainable policies. The model is also useful from the transportation planner's perspective, as it allows determining the financial need of companies when faced with regulatory policies. Because of the non-linearities, non-convexity, and non-continuous function of the S-MJRP, in Chapter 5 was developed a three-level heuristic based on GAs and a GRASP algorithm (Jaller et al., 2019). The authors conducted a number of empirical analyses that evidence the trade-off between capital investments in zero-emission vehicles and logistics costs to abide by the potential regulatory requirements. More importantly, the results of S-MJRP provide insights for the particular examples, between the contributions to emission reductions resulting from the direct benefits from a cleaner fleet, and the benefits realized from the joint replenishment. In other words, the model shows the benefits from technological improvements as well as optimal logistics operations.

An important question, then, is what are the potential implications of collaboration under different objectives? To answer this question, for example, the S-MJRP could be extended to consider the collaboration of additional players. Under the same type of examples, as in Jaller et al. (2019), the extension could explore the benefits and potential of collaborative practices in the supply chain as a financial alternative to leverage the purchase of cleaner (zero- or near-zero emission) vehicles, or lower emission operations at potentially higher costs. The findings from Chapter 3 (Otero-Palencia, Amaya-Mier, & Yie-Pinedo, 2018) suggest that these collaborations can result in operations at reduced costs, which could help hedge potential cost increases due to lower emission operations. For instance, assuming that the interest is reducing transport-related emissions, a strategy that sacrifices holding costs by increasing shipment sizes and reducing delivery frequency would result in lower transport-related emissions. From a practical perspective, having big investments in inventory represents a high risk for depreciation and eventual unit losses. Even worse, cash flow is compromised since the money invested in inventory cannot be recovered until their sale, which coupled with other investments in new vehicle technologies or equipment could amplify the risks. Lack of cash flow represents one of the most common reasons for bankruptcy. One of the most practical ways to calculate the cash flow is through a metric known as Cash to Cash (Farris and Hutchison, 2002). This metric measures the time that each dollar invested in inventory returns to the company. The smaller the metric value, the more solvent the company is. A similar analogy could be made to investments in new technologies, under the JRP modeling framework. This is of particular importance to SMEs, which may not have the financial wherewithal to adopt new technologies (e.g., vehicles, equipment), or the capacity to hold larger inventories. Nevertheless, benefits from collaborative practices are expected from economies of scale, and the shared optimal use of resources.

Integrating the previous discussion with the analyses in previous sections, a natural extension of the JRP could incorporate, for example, stochastic effects in demand, transport and lead times; warehouse and budgetary constraints; different types of transport units (vehicle technologies); collaboration among agents; coordination costs and requirements; and different objectives which could include logistics, environmental, health, and other costs, and performance measures such as cash to cash.

Collaborative practices have demonstrated utility by improving the cost efficiency of inventory management processes, where savings could translate to millions of dollars. In this sense, they are especially beneficial for SMEs, which typically face financial constraints. As such, S-CJRP increases the chances of realizing the promised benefits of collaboration in practice. Similarly, when SMEs are also forced to consider sustainability policies, M-SJRP is especially well suited to these kinds of analyses.

Despite the promising results from collaboration, there is always a trade-off between the expected surplus and the cost of coordinating the diverse collaborating parties of a coalition. Moreover, the promise of such savings can be put at risk when joint replenishments are underperformed, and/or when other things go wrong. Examples of potential issues include when vendors fail to deliver on time, or buyers are late in ordering, or when there are errors in the merge-in-transit operations due to human error, lack of visibility, inappropriate security stock, and the like, leading to re-processing costs and lost sales. All of these issues arise from inappropriate coordination, which suggests that effective coalition management is critically important to reduce cost overruns (Arshinder et al., 2008) and to preserve the collaboration surplus.

An initial consideration is, should coordination be insourced or outsourced? The coordination could be insourced (i.e., the responsibility of one or several players) or outsourced (e.g., a 3PL); in either case, the responsible entity will be denoted here as the Coordinator. The coordination task represents a sustainable source of expenditures, a strategic asset which provides the required coordination and efficiency of the augmented supply system, which is why determining the best way to perform the collaborative strategy is an important concern. This work argue that it is preferable to outsource the supply chain coordination, for two main reasons: first, it is reasonable to assume that a 3PL already has the experience and the technology (ERP, tracking systems, facilities at site, etc.) to handle the task, thus outperforming any given player that would be undertaking the task but without familiarity. Second, if the coalition internally assumes the coordination task with proprietary resources, any incurred overruns would be internally assumed as well. Outsourcing as an alternative transfers the supply chain risk to a neutral and capable party, as such, the coordination role can assume any cost incurred by misguided directions or lack of coordination, outperforming insourcing options. The 3PL coordination cost is an extra charge that is justified by reassuring the replenishment scheduled fulfillment. The 3PL's experience and expertise in support technologies, such as ERP[6] or BPM[7], is assumed by definition, and could turn into a strategic advantage. Along the

[6] Enterprise resource planning

[7] Business process management

same lines, an uninterrupted and efficient operation provided by a 3PL coordinator could attract additional potential players aiming to reduce their logistics costs.

In Chapter 3 the situation where the 3PL exerts effective control over the chain was tested, overseeing the real demand and inventory of each player and performing an appropriate match with the available transport and warehouse capacity to perform coordinated dispatches. In this way, it has the ability to make replenishment adjustments in a timely manner, always taking into account original orders generated from the S-CJRP. Even though 3PL charges could raise the total cost, the level of service could be improved, which supports the use of a 3PL in charge of the coordination role.

Another important consideration is how much a lack of coordination would cost. Chapter 4 (Otero-Palencia, Carlos; Amaya-Mier, René; Montoya-Torres, 2019) illustrate a simple case of three players individually facing limited storage capacities and with warehouse capacity expansion being cost-prohibitive. Acting as a coalition under the S-CJRP approach, and with the increased economy of scale allowed by collaborating, the players could possibly negotiate better agreements with 3PL companies, to reduce their individual investment costs to expand their warehouse capacities. For illustration purposes, assuming a fare reduction of 10% on both the ordering and holding costs by negotiating with 3PLs, S-CJRP could yield individual savings of 26.7%, 32.49% and 47.85% for the players. The former savings can only be guaranteed if no player misses the replenishment schedule. Any lack of coordination could significantly increase the total cost.

Among other questions to answer and other potential extensions, as well. The proposed model may incorporate possible quantity discounts, which could require an extra storage capacity. An underlying question: Is it really cost-efficient to take advantage of quantity discounts? Furthermore, one of the assumptions that should be accounted for in future works is related to cargo compatibility, since some cargo could have constraints to be merged together. Beyond, the current model scope ends with the cargo breakdown in a destination close the players. Although the last mile distribution issue is still not addressed, its exploration could yield potential extra savings. E.g., the players could share transportation units to reduce the last mile unit cost. Furthermore, acting as a coalition the players could acquire more efficient transportation resources, not affordable in an individual way, such as electric trucks, electric bikes or automated vehicles. With the increase in scale, players can improve the use of resources thus reducing the unit transportation cost, but also the use of electric vehicles means significant savings in fuel costs. Additionally, the use of these vehicles allows reducing carbon emissions, which could be mandatory in some countries.

On the other hand, at a more global logistic level, future research may explore different types of companies according to some classification criteria, such as size, type of load, location, or other characteristics, to determine targeted efficiencies according to classification in reducing emissions. Other research direction consists of designing a model to optimize the global system's emissions (for example, at the city level), such that companies and governments work together to share resources to minimize global emissions restricted by the available capital. Wieser (2011), for instance, discusses that global optimization could generate better impacts at the system level than would be possible through individual optimization per supply chain. The impact generated on the system by a single company minimizing emissions could be less than what might be realized by a group of companies reducing emissions, even not necessarily to the minimum, using a smaller or equal capital amount. Finally, some authors assert that supply chain sustainability decisions should consider a wide scope to generate a greater impact (Jaegler and Sarkis 2014; Lion et al. 2016). While this study only focuses on the supplier-retailer segment to keep it manageable, a future research direction could analyze the impacts of sustainable policies along the supply chain, not only to assure a greater emissions reduction, but also to boost the implementation of clean technologies more efficiently.

REFERENCES

Andreoli, T. (1995). VMI confab examines value-added services. *Discount Store News*, *34*, 4-61

Ai, X.-Y., Zhang, J.-L., & Wang, L. (2017). Optimal joint replenishment policy for multiple non-instantaneous deteriorating items. *International Journal of Production Research*, 1–18. https://doi.org/10.1080/00207543.2016.1276306

Aksoy, Y., & Erenguc, S. S. (1988). Multi-Item Inventory Models with Co-ordinated Replenishments: A Survey. *International Journal of Operations & Production Management*, *8*(1), 63–73. https://doi.org/10.1108/eb054814

Allen, D. H., & Allen, D. H. (1991). *Economic evaluation of projects, a guide*. Institution of Chemical Engineers. Retrieved from https://books.google.com/books?id=NgokwMxFD8EC&printsec=frontcover&dq=Analysis+and+evaluation+projects+investment+book&hl=es&sa=X&ved=0ahUKEwjIpc_x0eTdAhXRFjQIHfALD-wQ6AEIJzAA#v=onepage&q=Analysis and evaluation projects investment book&f=false

Alp, O., Ulk, G., & Nasuh C, B. (2014). Coordinated Logistics : Joint Replenishment with Capacitated Transportation for a Supply Chain, *23*(1), 110–126. https://doi.org/10.1111/poms.12041

Amaya, C. A., Carvajal, J., & Castaño, F. (2013). A heuristic framework based on linear programming to solve the constrained joint replenishment problem (C-JRP). *International Journal of Production Economics*, *144*(1), 243–247. https://doi.org/10.1016/J.IJPE.2013.02.008

Amaya, R., Barbosa, R., Borrero, A., Ching, K., Gómez, L., González, S., … Oyola, J. (2018). *Intervención sobre Prácticas Integrativas en el Clúster de Logística del Atlántico: Cadenas Logísticas De Comercio Exterior*. (R. Amaya, Ed.) (Primera Ed). Barranquilla, Colombia: Ediciones Uninorte.

Anily, S., & Haviv, M. (2007). The Cost Allocation Problem for the First Order Interaction Joint Replenishment Model. *Operations Research*, *55*(2), 292–302. https://doi.org/10.1287/opre.1060.0346

Arango Serna, M. D., Adarme Jaimes, W., & Zapata Cortés, J. A. (2013). Inventarios Colaborativos En La Optimización De La Cadena De Suministros. *DYNA: Revista de La Facultad de Minas. Universidad Nacional de Colombia. Sede Medellín*, *80*(181), 71–80. Retrieved from http://www.revistas.unal.edu.co/index.php/dyna/article/viewFile/37629/42259

Arkin, E., Joneja, D., & Roundy, R. (1989). Computational complexity of uncapacitated multi-echelon production planning problems. *Operations Research Letters*, *8*(2), 61–66. https://doi.org/10.1016/0167-6377(89)90001-1

Arshinder, Kanda, A., & Deshmukh, S. G. (2008). Supply chain coordination: Perspectives, empirical studies and research directions. *Institutional Perspectives on Supply Chain Management*, *115*(2), 316–335. https://doi.org/DOI: 10.1016/j.ijpe.2008.05.011

Atkins, D. R., & Iyogun, P. O. (1988). Periodic Versus “Can-Order” Policies for Coordinated Multi-Item

Inventory Systems. *Management Science*, *34*(6), 791–796. https://doi.org/10.1287/mnsc.34.6.791

Bäckstrand, J. (2007). Levels of Interactions in Supply Chain Relations. Retrieved from https://research.chalmers.se/publication/44969

Ballou, R. H. (2004). *Lógistica, Administración de la Cadena de suministro*. *Pearson Educación*. https://doi.org/10.1007/s13398-014-0173-7.2

Ballou, R. H. (2007). *Business logistics/supply chain management* (5th ed.). Person Education.

Banco Interamericano de Desarrollo, D. de T. (2014). *Índice de gastos logísticos*. Retrieved from http://logisticsportal.iadb.org/node/4210

Banco Mundial, C. F. I. (2007). *Reporte Doing Business 2007*. Washington. Retrieved from http://espanol.doingbusiness.org/reports/global-reports/doing-business-2007

Banco Mundial, C. F. I. (2016). *Comercio transfronterizo - Doing Business - Banco Mundial*. Washington. Retrieved from espanol.doingbusiness.org/Methodology/Trading-Across-Borders

Barratt, M. (2004). Understanding the meaning of collaboration in the supply chain. *Supply Chain Management: An International Journal*, *9*(1), 30–42. https://doi.org/10.1108/13598540410517566

Barratt, M. (2007). Supply Chain Management: An International Journal"Combining vertical and horizontal collaboration for transport optimisation", Supply Chain Management: An Understanding the meaning of collaboration in the supply chain. *International Journal Iss International Journal of Physical Distribution & Logistics Management Iss International Journal*, *9*(3), 30–42. Retrieved from http://dx.doi.org/10.1108/13598540410517566

Bartholdi, J., & Kemahlioğlu-Ziya, E. (2005). Using Shapley Value to Allocate Savings in A Supply Chain. *Supply Chain Optimization*, 169–208. Retrieved from http://dx.doi.org/10.1007/0-387-26281-4_6

Bienkowski, M., Byrka, J., Chrobak, M., Dobbs, N., Nowicki, T., Sviridenko, M., … Young, N. E. (2015). Approximation algorithms for the joint replenishment problem with deadlines. *Journal of Scheduling*, *18*(6), 545–560. https://doi.org/10.1007/s10951-014-0392-y

Bierman, H. J., & Smidt, S. (2012). *The capital budgeting decision: economic analysis of investment projects*. Retrieved from https://books.google.com/books?hl=es&lr=&id=pHXWf71pkPsC&oi=fnd&pg=PR1&dq=Analysis+and+evaluation+projects+investment+book&ots=t5UCsQ1sQ1&sig=MkZ6KRUc2apLb5sLry1Nr8hfB94#v=onepage&q=Analysis and evaluation projects investment book&f=false

Bititci, U., Turner, T., Mackay, D., Kearney, D., Parung, J., & Walters, D. (2007). Managing synergy in collaborative enterprises. *Production Planning & Control*, *18*(6), 454–465. https://doi.org/10.1080/09537280701494990

Braglia, M., Castellano, D., & Gallo, M. (2016). An extension of the stochastic Joint-Replenishment Problem under the class of cyclic policies. *Operations Research Letters*, *44*(2), 278–284. https://doi.org/10.1016/j.orl.2016.02.004

Brahimi, N., Absi, N., Dauzère-Pérès, S., & Kedad-Sidhoum, S. (2015). Models and Lagrangian heuristics for a two-level lot-sizing problem with bounded inventory. *OR Spectrum*, *37*(4), 983–1006. https://doi.org/10.1007/s00291-015-0404-0

Bravo, J. J., & Vidal, C. J. (2013). Freight transportation function in supply chain optimization models: A critical review of recent trends. *Expert Systems with Applications*, *40*(17), 6742–6757. https://doi.org/10.1016/j.eswa.2013.06.015

Cachon, G., & Netessine, S. (2004). Game theory in supply chain analysis. *Handbook of Quantitative Supply Chain*. Retrieved from http://link.springer.com/chapter/10.1007/978-1-4020-7953-5_2

Cachon, G. P., & Netessine, S. (2006). Game theory in supply chain analysis. *Tutorials in Operations Research: Models, Methods, and Applications for Innovative Decision Making*, 1–34. https://doi.org/10.1287/educ.1053.0000

Chan, C. K., Cheung, B. K.-S., & Langevin, A. (2003). Solving the multi-buyer joint replenishment problem with a modified genetic algorithm. *Transportation Research Part B: Methodological*, *37*(3), 291–299. https://doi.org/10.1016/S0191-2615(02)00015-2

Chan, F. T. S., & Prakash, A. (2012). Inventory management in a lateral collaborative manufacturing supply chain: a simulation study. *International Journal of Production Research*, *50*(16), 4670–4685. https://doi.org/10.1080/00207543.2011.628709

Chen, T. H., & Chen, J. M. (2005). Optimizing supply chain collaboration based on joint replenishment and channel coordination. *Transportation Research Part E: Logistics and Transportation Review*, *41*(4), 261–285. https://doi.org/10.1016/j.tre.2004.06.003

Cheung, M., Elmachtoub, A. N., Levi, R., & Shmoys, D. B. (2016). The submodular joint replenishment problem. *Mathematical Programming*, *158*(1–2), 207–233. https://doi.org/10.1007/s10107-015-0920-3

Chopra, S., & Meindl, P. (2007). Supply Chain Measurement: Strategy, Planning and Operation, Prentice-Hall. Retrieved from http://feminineinquiry.com/supply-chain-management-strategy-planning-and-operation-download-books-safe-sunil-chopra-peter-meindl.pdf

Chopra, S., & Meindl, P. (2013). *Administración de la cadena de suministro*. *Estrategia, planeación y operación*. https://doi.org/10.1017/CBO9781107415324.004

Contreras, J., Gross, G., Manuel, J., & Ignacio, J. (2009). An incentive-based mechanism for transmission asset investment. *Decision Support Systems*, *47*, 22–31. https://doi.org/10.1016/j.dss.2008.12.005

Danese, P. (2006). The extended VMI for coordinating the whole supply network. *Journal of Manufacturing Technology Management*, *17*(7), 888–907. https://doi.org/10.1108/17410380610688223

Daza, A. M., Otero, C., & Paternina, C. (2018). Maximization of profits in import activities through a hybrid algorithm based on fictional games with multiple suppliers. In *The Second European International Conference on Industrial Engineering and Operations Management* (p. 358'367). Retrieved from http://www.ieomsociety.org/paris2018/papers/69.pdf

Defryn, C., Vanovermeire, C., Sörensen, K., Breedam, A. Van, Vannieuwenhuyse, B., & Verstrepen, S. (2013). Gain sharing in horizontal logistic collaboration A case study in the fresh fruit and vegetables sector.

Deng, X., & Papadimitriou, C. H. (1994). On the Complexity of Cooperative Solution Concepts. *Mathematics of Operations Research*, *19*(2), 257–266. https://doi.org/10.1287/moor.19.2.257

Department of Economic and Social Affairs, U. N. (2014). *World Urbanization Prospects: The 2014 Revision*. Retrieved from https://esa.un.org/unpd/wup/publications/files/wup2014-highlights.pdf

Disney, S. M., & Towill, D. R. (2003). *Vendor-managed inventory and bullwhip reduction in a two-level supply chain*. *International Journal of Operations & Production Management* (Vol. 23). https://doi.org/10.1108/01443570310476654

Doing Business (The World Bank Group). (2016). Doing Business 2017 Data Notes.

Dror, M., & Hartman, B. C. (2007). Shipment Consolidation: Who Pays for It and How Much? *Management Science*, *53*(1), 78–87. https://doi.org/10.1287/mnsc.1060.0607

Dror, M., & Hartman, B. C. (2011). Survey of cooperative inventory games and extensions. *Journal of the Operational Research Society*, *62*(4), 565–580. https://doi.org/10.1057/jors.2010.65

Eijs, M. Van, Heuts, R., & Kleijnen, J. (1992). Analysis and comparison of two strategies for multi-item inventory systems with joint replenishment costs. *European Journal of Operational*. Retrieved from http://www.sciencedirect.com/science/article/pii/037722179290197H

Elomri, A., Ghaffari, A., Jemai, Z., & Dallery, Y. (2012). Coalition Formation and Cost Allocation for Joint Replenishment Systems. *Production and Operations Management*, *21*(6), 1015–1027. https://doi.org/10.1111/j.1937-5956.2012.01333.x

Elomri, A., Ghaffari, A., Jemai, Z., & Dallery, Y. (2013). Cost allocation in a full truckload shipment consolidation game. *International Journal of Inventory Research*, *2*(1/2), 127. https://doi.org/10.1504/IJIR.2013.058344

Ertogral, K., Darwish, M., & Ben-Daya, M. (2007). Production and shipment lot sizing in a vendor–buyer supply chain with transportation cost. *European Journal of Operational*. Retrieved from http://www.sciencedirect.com/science/article/pii/S0377221705008714

Eynan, A., & Kropp, D. H. (1998). Periodic review and joint replenishment in stochastic demand environments. *IIE Transactions*, *30*(11), 1025–1033. https://doi.org/10.1023/A:1007503629054

Fawcett, S. E., Magnan, G. M., & McCarter, M. W. (2008). A THREE-STAGE IMPLEMENTATION MODEL FOR SUPPLY CHAIN COLLABORATION. *Journal of Business Logistics*, *29*(1), 93–112. https://doi.org/10.1002/j.2158-1592.2008.tb00070.x

Fiestras-Janeiro, M. G., García-Jurado, I., Meca, A., & Mosquera, M. A. (2011). Cooperative game theory and inventory management. *European Journal of Operational Research*. https://doi.org/10.1016/j.ejor.2010.06.025

Fiestras-Janeiro, M. G., García-Jurado, I., Meca, A., & Mosquera, M. A. (2015). Cooperation on capacitated inventory situations with fixed holding costs. *European Journal of Operational Research*, *241*(3), 719–726. https://doi.org/10.1016/j.ejor.2014.09.016

Forkenbrock, D. J. (1999). External costs of intercity truck freight transportation. *Transportation Research Part A: Policy and Practice*, *33*(7–8), 505–526. https://doi.org/10.1016/S0965-8564(98)00068-8

Fung, R., Ma, X., & Lau, H. (2001). (T, S) policy for coordinated inventory replenishment systems under compound Poisson demands. *Production Planning & Control*.

Georgise, F. B., Thoben, K.-D., & Seifert, M. (2012). Adapting the SCOR model to suit the different scenarios: a literature review & research agenda. *International Journal of Business and Management*, *7*(6), 1–17. https://doi.org/10.5539/ijbm.v7n6p2

Goyal, S. (1975). Analysis of Joint Replenishment Inventory Systems with Resource Restriction. *Journal of the Operational Research Society*, *26*(S1), 197–203. https://doi.org/10.1057/jors.1975.42

Goyal, S., & Belton, A. (1979). On A Simple Method of Determining Order Quantities in Joint Replenishments under Deterministic Demand. *Management Science*, (604-604.).

Goyal, S. K., & Deshmukh, S. G. (1993). Discussion A note on “The economic ordering quantity for jointly replenishing items.” *The International Journal of Production Research*. Retrieved from http://www.tandfonline.com/doi/pdf/10.1080/00207549308956910

Hariga, M. (1994). Two New Heuristic Procedures for Joint the Replenishment Problem. *Palgrave Macmillan Journals on Behalf of the Operational Research Society*, *45*(4), 463–471.

Harris, F. W. (1913). How many parts to make at once. *The Magazine of Management*, *38*(2 (Feb, 1913)), 135–136.

Hartman, B. C., & Dror, M. (2003). Optimizing centralized inventory operations in a cooperative game theory setting. *IIE Transactions*. Retrieved from http://www.tandfonline.com/doi/abs/10.1080/07408170304363

Henao-Perez, A., Otero-Palencia, C., & Amaya-Mier, R. (2018). Muestra de cadenas de suministro diagnosticadas. In R. Amaya-Mier (Ed.), *Invervención sobre las prácticas integrativas en el clúster de logística del Atlántico.* (Primera Ed, pp. 63–126). Barranquilla: Ediciones Uninorte.

Hoen, K. M. R., Tan, T., Fransoo, J. C., & Van Houtum, G. J. (2014). Effect of carbon emission regulations on transport mode selection under stochastic demand. *Flexible Services and Manufacturing Journal*, *26*(1–2), 170–195. https://doi.org/10.1007/s10696-012-9151-6

Holguín-Veras, José; Jaller, Miguel; Destro, Lisa; Xuegang, (Jeff) Ban;, & Lawson, Catherine; Levinson, H. S. (2011). Freight Generation, Freight Trip Generation, and Perils of Using Constant Trip Rates. *Journal of the Transportation Research Board*, (2224), 68–81. https://doi.org/10.3141/2224-09

Holweg, M., Disney, S., Holmström, J., & Småros, J. (2005a). Supply Chain Collaboration:: Making Sense of the Strategy Continuum. *European Management Journal*, *23*(2), 170–181. https://doi.org/10.1016/j.emj.2005.02.008

Holweg, M., Disney, S., Holmström, J., & Småros, J. (2005b). Supply Chain Collaboration:: Making Sense of the Strategy Continuum. *European Management Journal*, *23*(2), 170–181. https://doi.org/DOI: 10.1016/j.emj.2005.02.008

Hoque, M. A. (2006). An optimal solution technique for the joint replenishment problem with storage and transport capacities and budget constraints. *European Journal of Operational Research*, *175*(2), 1033–1042. https://doi.org/10.1016/j.ejor.2005.06.022

Horvath, L. (2001). Collaboration: the key to value creation in supply chain management. *Supply Chain Management: An International Journal*, *6*(5), 205–207. https://doi.org/10.1108/EUM0000000006039

Hsu, H.-P., & Hsu, H.-M. (2008). Systematic modeling and implementation of a resource planning system for virtual enterprise by Predicate/Transition net. *Expert Systems with Applications*, *35*(4), 1841–1857. https://doi.org/10.1016/j.eswa.2007.08.082

Huan, S. H., Sheoran, S. U. K., & Wang, G. (2004). A review and analysis of supply chain operations reference (SCOR) model. *Supply Chain Management*, *9*(1), 23. https://doi.org/10.1108/13598540410517557

Ireland, R., & Bruce, R. (2000). CPFR: only the beginning of collaboration. *Supply Chain Management Review*, *4*(4), 80-88.

Jaegler, A., & Sarkis, J. (2014). The Theory and Practice of Sustainable Supply Chains. *Supply Chain Forum: An International Journal*, *15*(1), 2–5. https://doi.org/10.1080/16258312.2014.11517329

Jaller, Miguel; Otero-Palencia, Carlos; Yie-Pinedo, R. (2019). Inventory and Fleet Purchase Decision Under a Sustainable Regulatory Environment. *Supply Chain Forum: An International Journal(Manuscript Submitted for Publication)*.

Jaller, M., & Harvey, J. (2018). *Development of a Freight System Conceptualization and Impact Assessment (Fre-SCANDIA) Framework A Research Report from the National Center for Sustainable Transportation*. Retrieved from https://escholarship.org/uc/item/05g8p7tn

Jaller, M., Pineda, L., & Ambrose, H. (2018). Evaluating the Use of Zero-Emission Vehicles in Last Mile Deliveries. https://doi.org/10.7922/G2JM27TW

Jaller, M., Sánchez, S., Green, J., & Fandiño, M. (2016). Quantifying the Impacts of Sustainable City Logistics Measures in the Mexico City Metropolitan Area. *Transportation Research Procedia*, *12*, 613–626. https://doi.org/10.1016/J.TRPRO.2016.02.015

Johansen, S. G., & Melchiors, P. (2003). Can-order policy for the periodic-review joint replenishment problem. *Journal of the Operational Research Society*, *54*(3), 283–290. https://doi.org/10.1057/palgrave.jors.2601499

Kang, H.-Y., Lee, A. H. I., Wu, C.-W., & Lee, C.-H. (2016). An efficient method for dynamic-demand joint replenishment problem with multiple suppliers and multiple vehicles. *International Journal of Production Research*. https://doi.org/10.1080/00207543.2016.1218564

Kaspi, M., & Rosenblatt, M. (1983). An improvement of Silver's algorithm for the joint replenishment problem. *AIIE Transactions*. Retrieved from http://www.tandfonline.com/doi/abs/10.1080/05695558308974644

Kaspi, M., & Rosenblatt, M. J. (1985). The effectiveness of heuristic algorithms for multi-item inventory systems with joint replenishment costs. *International Journal of Production Research*, *23*(1), 109–116. https://doi.org/10.1080/00207548508904694

Kaspi, M., & Rosenblatt, M. J. (1991). On the economic ordering quantity for jointly replenished items. *International Journal of Production Research*, *29*(1), 107–114. https://doi.org/10.1080/00207549108930051

Kelle, P., Miller, P. A., & Akbulut, A. Y. (2007). Coordinating ordering/shipment policy for buyer and supplier: Numerical and empirical analysis of influencing factors. *International Journal of Production Economics*, *108*(1), 100–110. https://doi.org/10.1016/j.ijpe.2006.12.005

Kelley, P., & Hounsell, R. W. (2007). Engaging associates and unleashing productivity: The case for Simplified GainSharing. *Performance Improvement*, *46*(2), 30–34. https://doi.org/10.1002/pfi.106

Khouja, M., & Goyal, S. (2008). A review of the joint replenishment problem literature: 1989-2005. *European Journal of Operational Research*, *186*(1), 1–16.

Khouja, M., Michalewicz, Z., & Satoskar, S. S. (2000a). A comparison between genetic algorithms and the RAND method for solving the joint replenishment problem. *Production Planning & Control*, *11*(6), 556–564. https://doi.org/10.1080/095372800414115

Khouja, M., Michalewicz, Z., & Satoskar, S. S. (2000b). A comparison between genetic algorithms and the RAND method for solving the joint replenishment problem A comparison between genetic algorithms and the RAND method for solving the joint replenishment problem. *Production Planning & Control*, *11*(november). https://doi.org/10.1080/095372800414115

Kiesmüller, G. P. (2010). Multi-item inventory control with full truckloads: A comparison of aggregate and individual order triggering. *European Journal of Operational Research*, *200*(1), 54–62. https://doi.org/10.1016/j.ejor.2008.12.008

Krajewska, M. A., Kopfer, H., Laporte, G., Ropke, S., & Zaccour, G. (2008). Horizontal cooperation among freight carriers: request allocation and profit sharing. *Journal of the Operational Research Society*, *59*(11), 1483–1491. https://doi.org/10.1057/palgrave.jors.2602489

Le Blanc, H. M., van Krieken, M. G. C., Fleuren, H., & Krikke, H. R. (2004). Collector Managed Inventory, a Proactive Planning Approach to the Collection of Liquids Coming from End-of-Life Vehicles. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.557763

Lee, F., & Yao, M. (2003). A global optimum search algorithm for the joint replenishment problem under power-of-two policy. *Computers & Operations Research*. Retrieved from http://www.sciencedirect.com/science/article/pii/S0305054802000734

Leng, M., & Parlar, M. (2005). Game theoretic applications in supply chain management: A review. *INFOR*, *43*(3), 187–220. https://doi.org/10.1080/03155986.2005.11732725

Li, Q. (2004). Solving the multi-buyer joint replenishment problem with the RAND method. *Computers &*

Industrial Engineering, *46*(4), 755–762. https://doi.org/10.1016/J.CIE.2004.05.008

Lion, A., Macchion, L., Danese, P., & Vinelli, A. (2016). Sustainability approaches within the fashion industry: the supplier perspective. *Supply Chain Forum: An International Journal*, *17*(2), 95–108. https://doi.org/10.1080/16258312.2016.1176752

Meca, A., Timmer, J., García-Jurado, I., & Borm, P. (2004). Inventory games. *European Journal of Operational Research*, *156*(1), 127–139. https://doi.org/10.1016/S0377-2217(02)00913-X

Mehrjerdi, Y. Z. (2009). The collaborative supply chain. *Assembly Automation*, *29*(2), 127–136.

Miller, D. W., & Starr, M. K. (1962). *Inventory control: Theory and practice*. Englewood Clilfs, NJ: Practice Hall.

Montoya-Torres, J. R., & Ortiz-Vargas, D. A. (2014). Collaboration and information sharing in dyadic supply chains: A literature review over the period 2000–2012. *Estudios Gerenciales*, *30*(133), 343–354. https://doi.org/10.1016/J.ESTGER.2014.05.006

Moon, I. K., & Cha, B. C. (2006). The joint replenishment problem with resource restriction. *European Journal of Operational Research*, *173*(1), 190–198. https://doi.org/10.1016/j.ejor.2004.11.020

Mustafa Tanrikulu, M., Şen, A., & Alp, O. (2010). A joint replenishment policy with individual control and constant size orders. *International Journal of Production Research*, *48*(14), 4253–4271. https://doi.org/10.1080/00207540802662904

Myerson, R. B. (1991). Game theory: analysis of conflict. *Harvard University*.

Naesens, K., Gelders, L., & Pintelon, L. (2007). A swift response tool for measuring the strategic fit for resource pooling: a case study. *Management Decision*, *45*(3), 434–449. https://doi.org/10.1108/00251740710745061

Nagarajan, M., & Sošić, G. (2008). Game-theoretic analysis of cooperation among supply chain agents: Review and extensions. *European Journal of Operational Research*, *187*(3), 719–745. https://doi.org/10.1016/J.EJOR.2006.05.045

Narayanan, A., & Robinson, P. (2010). Evaluation of joint replenishment lot-sizing procedures in rolling horizon planning systems. *International Journal of Production Economics*, *127*(1), 85–94. https://doi.org/10.1016/J.IJPE.2010.04.038

Narus, J. A., & Anderson, J. C. (1996). *Harvard business review. Harvard Business Review* (Vol. 74). Graduate School of Business Administration, Harvard University. Retrieved from https://www.scholars.northwestern.edu/en/publications/rethinking-distribution-adaptive-channels

Neumann, L. J., & Morgenstern, O. (1944). *Theory of games and economic behavior*. Retrieved from http://www.mtas.ru/search/search_results.php?publication_id=20032

Nicholson, J. D., LaPlaca, P., Al-Abdin, A., Breese, R., & Khan, Z. (2018). What do introduction sections tell us about the intent of scholarly work: A contribution on contributions. *Industrial Marketing Management*, *73*(March), 206–219. https://doi.org/10.1016/j.indmarman.2018.02.014

Nilsson, A., & Silver, E. A. (2007). A simple improvement on Silver's heuristic for the joint replenishment problem. *Journal of the Operational Research Society*, *59*(10), 1415–1421. https://doi.org/10.1057/palgrave.jors.2602446

Nocturne, D. (1973). Note-Economic Ordering Frequency for Several Items Jointly Replenished. *Management Science*. Retrieved from http://pubsonline.informs.org/doi/abs/10.1287/mnsc.19.9.1093

Olsen, A. (2005). An evolutionary algorithm to solve the joint replenishment problem using direct grouping. *Computers & Industrial Engineering*. Retrieved from http://www.sciencedirect.com/science/article/pii/S0360835205000112

Ongkunaruk, P., Wahab, M. I. M., & Chen, Y. (2016). A genetic algorithm for a joint replenishment problem with resource and shipment constraints and defective items. *International Journal of Production Economics*, *175*, 142–152. https://doi.org/10.1016/j.ijpe.2016.02.012

Otero-Palencia, Carlos; Amaya-Mier, René; Montoya-Torres, J. (2019). A Collaborative logistical cost-reduction approach for non-competitive small-and medium-sized enterprises: exploring S-CJRP coordination and variability aspects through Discrete-Events Simulation. *Transportation Research Part A: Policy and Practice (Manuscript Submitted for Publication)*.

Otero-Palencia, Carlos; Amaya-Mier, R. (2016). Quick methodology based in the SCOR model for supply chains reengineering of international trade. In *Proceedings of the International Conference on Industrial Engineering and Operations Management* (pp. 2894–2895). Kuala Lumpur, Malaysia,: IEOM Society. Retrieved from http://ieomsociety.org/ieom_2016/pdfs/556.pdf

Otero-Palencia, Carlos Amaya-Mier, R., Motoya-Torres, J. R., & Jaller, M. (2020). Collaborative Inventory Replenishment: Discussions and Insights of a Cost-effective Alternative for Non-competitive Small and Medium-sized Enterprises. In Y. Hugo, C. Mejía, & M. Mattos (Eds.), *Supply Chain Management and Logistics in Latin America*. Emerald Publishing.

Otero-Palencia, C., Amaya-Mier, R., & Borrero, A. (2018). Desarrollos Metodológicos. In R. Amaya-Mier (Ed.), *Invervención sobre las prácticas integrativas en el clúster de logística del Atlántico.* (Primera Ed, pp. 7–62). Barranquilla: Ediciones Uninorte.

Otero-Palencia, C., Amaya-Mier, R., & Yie-Pinedo, R. (2018). A stochastic joint replenishment problem considering transportation and warehouse constraints with gainsharing by Shapley value allocation. *International Journal of Production Research*, *57*(10), 3036–3059. https://doi.org/10.1080/00207543.2018.1526418

Otero, C., & Amaya, R. (2017). A cost-effective collaborative inventory management strategy between non-competitor companies -A case study. In *Proceedings of the International Conference on Industrial Engineering and Operations Management* (pp. 948–960). Retrieved from http://ieomsociety.org/bogota2017/papers/235.pdf

Özen, U., Sošić, G., & Slikker, M. (2012). A collaborative decentralized distribution system with demand forecast updates. *European Journal of Operational Research*, *216*(3), 573–583. https://doi.org/10.1016/j.ejor.2011.07.055

Padmanabhan, G., Vrat, P., Padmanabhant, G., & Vratt, P. (1990). International Journal of Systems Science Inventory model with a mixture of back orders and lost sales Inventory model with a mixture of back orders and lost sales, *21*(8), 1721–1726. https://doi.org/10.1080/00207729008910488

Pantumsinchai, P. (1992). a Comparison of 3 Joint Ordering Inventory Policies. *Decision Sciences*, *23*(1), 111–127. https://doi.org/10.1111/j.1540-5915.1992.tb00379.x

Paul, S., Wahab, M. I. M., & Ongkunaruk, P. (2014). Joint replenishment with imperfect items and price discount. *Computers & Industrial Engineering*, *74*, 179–185. https://doi.org/10.1016/J.CIE.2014.05.015

Peterson, R., & Silver, E. A. (1979). Decision Systems for Inventory Management and Production Planning. *New York: Wiley*.

Porras, E., & Dekker, R. (2006). An efficient optimal solution method for the joint replenishment problem with minimum order quantities. *European Journal of Operational Research*, *174*(3), 1595–1615. https://doi.org/10.1016/j.ejor.2005.02.056

Porteus, E. L. (1990). Chapter 12 Stochastic inventory theory. *Handbooks in Operations Research and Management Science*, *2*, 605–652. https://doi.org/10.1016/S0927-0507(05)80176-8

Procolombia. (2015). Matriz de Costos de D.F.I. por Modalidad de Transporte. Retrieved from http://goo.gl/NwyEqn

Qu, H., Wang, L., & Liu, R. (2015). A contrastive study of the stochastic location-inventory problem with joint replenishment and independent replenishment. *Expert Systems with Applications*, *42*(4), 2061–2072. https://doi.org/10.1016/J.ESWA.2014.10.017

Rayburn, L. G. (1999). Contabilidad y administración de costos. Retrieved from http://www.sidalc.net/cgi-bin/wxis.exe/?IsisScript=CEPALFE.xis&method=post&formato=2&cantidad=1&expresion=mfn=007083

Schmeidler, D. (1969). The Nucleolus of a Characteristic Function Game. *SIAM Journal on Applied Mathematics*, *17*(6), 1163–1170. https://doi.org/10.1137/0117107

Shapley, L. . (1953). *A value por n-person, en H. Khun y A. Tucker (eds), Contributions to the theory.* New Jersey: A Princeton University Press.

Shapley, L. . (1967). On balanced sets and cores. *Naval Research Logistics Quarterly*. Retrieved from http://onlinelibrary.wiley.com/doi/10.1002/nav.3800140404/abstract

Silver, E. A. (1974). A control system for coordinated inventory replenishment. *International Journal of Production Research*, *12*, 647–671. https://doi.org/10.1080/00207547408919583

Silver, E. A. (1976). A Simple Method of Determining Order Quantities in Joint Replenishments Under Deterministic Demand. *Management Science*, *22*(12), 1351–1361. https://doi.org/10.1287/mnsc.22.12.1351

Silver, E. A., Pyke, D. F., & Peterson, R. (1998). Inventory Management and Production Planning and Scheduling. *Managerial and Decision Economics*, *11*(October 2015), 297–315. https://doi.org/10.1002/mde.4090110504

Simatupang, T. M., & Sridharan, R. (2002). The Collaborative Supply Chain. *The International Journal of Logistics Management*, *13*(1), 15–30. https://doi.org/10.1108/09574090210806333

Simatupang, T. M., & Sridharan, R. (2005). An integrative framework for supply chain collaboration. *The International Journal of Logistics Management*, *16*(2), 257–274. https://doi.org/10.1108/09574090510634548

Simchi-Levi, D., Kaminsky, P., & Simchi-Levi, E. (2003). *Designing and managing the supply chain: concepts, strategies, and case studies*. *Book* (Vol. 3). https://doi.org/Book Review

Singer, M., & Donoso, P. (2007). Internal supply chain management in the Chilean sawmill industry. *International Journal of Operations and Production Management*, *27*(5), 524–541. https://doi.org/10.1108/01443570710742393

Skjoett-Larsen, T., Thernøe, C., & Andresen, C. (2003). Supply chain collaboration. *International Journal of Physical Distribution & Logistics Management*, *33*(6), 531–549. https://doi.org/10.1108/09600030310492788

Slikker, M., & Nouweland, A. (2001). *Social and Economic Networks in Cooperative Game Theory*. Springer US.

Småros, J., Lehtonen, J., Appelqvist, P., & Holmström, J. (2003). The impact of increasing demand visibility on production and inventory control efficiency. *International Journal of Physical Distribution & Logistics Management*, *33*(4), 336–354. https://doi.org/10.1108/09600030310478801

Song, J.-S. (1994). The Effect of Leadtime Uncertainty in a Simple Stochastic Inventory Model. *Management Science*, *40*(5), 603–613. https://doi.org/10.1287/mnsc.40.5.603

Stank, T. P., Keller, S. B., & Daugherty, P. J. (2001). SUPPLY CHAIN COLLABORATION AND LOGISTICAL SERVICE PERFORMANCE. *Journal of Business Logistics*, *22*(1), 29–48. https://doi.org/10.1002/j.2158-1592.2001.tb00158.x

Stewart, G. (1997). Supply-chain operations reference model (SCOR): the first cross-industry framework for integrated supply-chain management. *Logistics Information Management*, *10*(2), 62–67. https://doi.org/10.1108/09576059710815716

Supply-Chain Council. (2008). Supply-Chain Operations Reference Model–SCOR Version 9.0. *Supply-Chain Council, Inc*.

Supply Chain Council. (2010). Supply Chain Operations Reference (SCOR ®) model. *Design*, *Version 10*, 0–23. https://doi.org/10.1108/13598540410517557

Taleizadeh, A. A. (2014). An EOQ model with partial backordering and advance payments for an evaporating item. *International Journal of Production Economics*, *155*, 185–193. https://doi.org/10.1016/j.ijpe.2014.01.023

Taleizadeh, A. A., Niaki, S. T. A., Aryanezhad, M. B., & Tafti, A. F. (2010). A genetic algorithm to optimize multiproduct multiconstraint inventory control systems with stochastic replenishment intervals and discount. *International Journal of Advanced Manufacturing Technology*, *51*(1–4), 311–323. https://doi.org/10.1007/s00170-010-2604-8

Tijs, S., Meca, A., & López, M. A. (2005). Benefit sharing in holding situations. *European Journal of Operational Research*, *162*(1), 251–269. https://doi.org/10.1016/J.EJOR.2003.06.030

Tsao, Y.-C., & Teng, W.-G. (2013). Heuristics for the joint multi-item replenishment problem under trade credits. *IMA Journal of Management Mathematics*, *24*(1), 63–77. https://doi.org/10.1093/imaman/dps004

Tsao, Yu-Chung, & Sheen, G.-J. (2012). A multi-item supply chain with credit periods and weight freight cost discounts. *International Journal of Production Economics*, *135*(1), 106–115. https://doi.org/10.1016/J.IJPE.2010.11.013

U.S. Department of Energy, & Office of Scientific and Technical Information. (2013). Trends in global CO2 emissions. 2013 Report (Technical Report) | ETDEWEB. Retrieved February 26, 2019, from https://www.osti.gov/etdeweb/biblio/22176292

Vanovermeire, C., Sörensen, K., Van Breedam, A., Vannieuwenhuyse, B., & Verstrepen, S. (2014). Horizontal logistics collaboration: decreasing costs through flexibility and an adequate cost allocation strategy. *International Journal of Logistics Research and Applications*, *17*(4), 339–355. https://doi.org/10.1080/13675567.2013.865719

Viswanathan, S. (1996). A new optimal algorithm for the joint replenishment problem. *Journal of the Operational Research Society*.

Viswanathan, S. (2002). On optimal algorithms for the joint replenishment problem. *Journal of the Operational Research Society*, *53*(11), 1286–1290. https://doi.org/10.1057/palgrave.jors.2601445

Wang, L., Dun, C.-X., Lee, C.-G., Fu, Q.-L., & Zeng, Y.-R. (2013). Model and algorithm for fuzzy joint replenishment and delivery scheduling without explicit membership function. *The International Journal of Advanced Manufacturing Technology*, *66*(9–12), 1907–1920. https://doi.org/10.1007/s00170-012-4469-5

Wieser, P. (2011). From Health Logistics to Health Supply Chain Management. *Supply Chain Forum: An International Journal*, *12*(1), 4–13. https://doi.org/10.1080/16258312.2011.11517249

World Bank. (2007). *Logistic Performance Index Report: Connecting to Compete 2007 Trade Logistics in the Global Economy*. Washington. Retrieved from http://siteresources.worldbank.org/INTTLF/Resources/lpireport.pdf

World Bank. (2014). *Doing business 2015: Going beyond efficiency* (Vol. 12th Editi). Washinton DC, USA. https://doi.org/10.1596/978-1-4648-0351-2

World Bank. (2018). International Scorecard . Retrieved June 16, 2020, from https://lpi.worldbank.org/international/scorecard

World Bank. (2019). Stepping up Climate Adaptation and Resilience in Africa. Retrieved March 24, 2019, from https://www.worldbank.org/en/news/feature/2019/03/11/stepping-up-climate-adaptation-and-resilience-in-africa

World Bank. (2020a). Doing Business Economy Profile of Colombia, 1–68.

World Bank. (2020b). Doing Business rankings. Retrieved June 16, 2020, from https://www.doingbusiness.org/en/rankings

Yao, M.-J., & Huang, J.-Y. (2017). Optimal lot-sizing and joint replenishment strategy under a piecewise linear warehousing cost structure. *Journal of Intelligent Manufacturing*, *28*(3), 791–803. https://doi.org/10.1007/s10845-014-1027-z

Yousefi, O., Aryanezhad, M., Sadjadi, S. J., & Shahin, A. (2012). Developing a multi-objective, multi-item inventory model and three algorithms for its solution. *J Zhejiang Univ-Sci C (Comput & Electron)*, *13*(8), 601–612. https://doi.org/10.1631/jzus.C1100384

Yu, J. C. P. (2010). A COLLABORATIVE DETERIORATING INVENTORY SYSTEM WITH IMPERFECT QUALITY AND SHORTAGE BACKORDERING. *International Journal of Electronic Business Management*, *8*(3), 231–238. Retrieved from http://search.proquest.com/docview/846937501?pq-origsite=gscholar

Zavanella, L., & Zanoni, S. (2009). A one-vendor multi-buyer integrated production-inventory model: The ‘Consignment Stock’ case. *International Journal of Production Economics*, *118*(1), 225–232. https://doi.org/10.1016/j.ijpe.2008.08.044

Zhang, J. (2009). Cost Allocation for Joint Replenishment Models. *Operations Research*, *57*(1), 146–156. https://doi.org/10.1287/opre.1070.0491

Zhang, T., Liang, L., Yu, Y., & Yu, Y. (2007). An integrated vendor-managed inventory model for a two-echelon system with order cost reduction. *International Journal of Production Economics*, *109*(1), 241–253. https://doi.org/10.1016/j.ijpe.2006.12.051

APPENDIX A: COMPLEXITY PROOF S-CJRP SOLUTION ALGORITHM

Algorithm complexity proof

The simplest JPR deterministic version is proven to be a NP-hard problem. The solution methodology hereby proposed is based on a simple chromosome and quick mutation and crossover functions. It can be shown that the complexity of the GA's is proportional to the value of its parameters. Therefore, it is possible to adjust these parameters to reduce the computational time, without decreasing the quality of our solutions. Below we explain the computation of the complexity of our GA, which is given by the following expression:

$$\mathrm{T}(n,p,m,c,G) = p * \mathrm{F}(n) + G * [p * \mathrm{L}(n) + m * p * \mathrm{D}(n) + c * p * \mathrm{H}(n)]$$

Where,

$p\ =\ Size\ of\ the\ population,$

$m\ =\ Percentage\ of\ the\ population\ to\ be\ mutated\ (< 1),$

$c\ =\ Percentage\ of\ the\ population\ to\ be\ crossed\ (< 1),$

$G\ =\ Number\ of\ generations,$

$F(n)\ =\ Complexity\ for\ generating\ a\ random\ chromosome,$

$H(n)\ =\ Complexity\ for\ crossover\ function,$

$D(n)\ =\ Complexity\ for\ mutation\ function,$

$L(n) =\ Complexity\ for\ read\ a\ chromosome.$

The term $p * \mathrm{F}(n)$ refers to the complexity of generating p random chromosomes, while the term $p * \mathrm{L}(n)$ refers to the time of reading the list of chromosomes at each iteration. Since our chromosome is a single vector of size n, where we randomly generate a number for each position, we could say that $\mathrm{F}(n) = \mathrm{L}(n) = \Theta(n)$. Then we can redefine these terms as follows:

$$p * \mathrm{F}(n) = p * \mathrm{L}(n) = p * \Theta(n) = \Theta(p * n)$$

Our mutation function is the random change of a percentage of the chromosome. For this reason $\mathrm{D}(n) = \Theta(n)$. Also our crossover function is a simple swaping between two chromosomes then $\mathrm{H}(n) = \mathrm{O}(2n) = \Theta(n)$.

Since m y c are both lower that one, we have the following:

$$m * p * \mathrm{D}(n) = m * p * \Theta(n) = \mathrm{O}(p * n)$$

$$c * p * \mathrm{H}(n) = c * p * \ \Theta(n) = \mathrm{O}(p * n)$$

Then,

$$\mathrm{T}(n, p, m, c, G) = \mathrm{T}(n, p, G) = \Theta(p * n) + G * [\Theta(p * n) + \mathrm{O}(p * n) + \mathrm{O}(p * n)] = \mathrm{O}(G * p * n)$$

The simplicity of the chromosome and the mutation and crossover functions results on a polynomial complexity function.

$$\mathrm{T}(n, p, G) = \mathrm{O}(G * p * n)$$