Sustainable Supply Chain Network Design Integrating Logistics Outsourcing Decisions in the Context of Uncertainties

Thèse en cotutelle
Doctorat en génie mécanique

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Sous la direction de :

Daoud Ait-Kadi, directeur de recherche
Nidhal Rezg, directeur de cotutelle

Résumé

Les fournisseurs de services logistiques (3PLs) possèdent des potentialités pour activer les pratiques de développement durables entre les différents partenaires d'une chaîne logistique (*Supply Chain* SC). Il existe un niveau optimal d'intégration des 3PLs en tant que fournisseurs, pour s'attendre à des performances opérationnelles élevées au sein de toute la SC. Ce niveau se traduit par la distinction des activités logistiques à externaliser de celles à effectuer en interne. Une fois que les activités logistiques externalisés sont stratégiquement identifiées, et tactiquement dimensionnées, elles doivent être effectuées par des 3PLs appropriés afin d'endurer les performances économiques ; sociales ; et environnementales de la SC. La présente thèse développe une approche holistique pour concevoir une SC durable intégrant les 3PLs, dans un contexte incertain d'affaires et politique de carbone.

Premièrement, une approche de modélisation stochastique en deux étapes est suggérée pour optimiser à la fois le niveau d'intégration des 3PLs, et le niveau d'investissement en technologies sobres au carbone, et ce dans le contexte d'une SC résiliente aux changements climatiques. Notre SC est structurée de façon à capturer trois principales préoccupations du *Supply Chain* Management d'une entreprise focale FC (e. g. le fabricant) : Sécurité d'approvisionnement, Segmentation de distribution, et Responsabilité élargie des producteurs. La première étape de l'approche de modélisation suggère un plan stochastique basé sur des scenarios plus probables, afin de capturer les incertitudes inhérentes à tout environnement d'affaires (e. g. la fluctuation de la demande des différents produits ; la qualité et la quantité de retour des produits déjà utilisés ; et l'évolution des différents coûts logistiques en fonction du temps). Puis, elle propose un modèle de programmation stochastique bi-objectif, multi-période, et multi-produit. Le modèle de programmation quadratique, et non linéaire consiste à minimiser simultanément le coût logistique total espéré, et les émissions de Gaz à effet de Serre de la SC fermée. L'exécution du modèle au moyen d'un algorithme basé sur la méthode Epsilon-contraint conduit à un ensemble de configurations Pareto optimales d'une SC dé-carbonisée, avant tout investissement en technologie sobre au carbone. Chacune de ces configurations sépare les activités logistiques à externaliser de celles à effectuer en interne. La deuxième étape de

l'approche de modélisation permet aux décideurs de choisir la meilleure configuration de la SC parmi les configurations Pareto optimales identifiées. Le concept de Prix du Carbone Interne est utilisé pour établir un plan stochastique du prix de carbone, dans le cadre d'un régime de déclaration volontaire du carbone. Nous proposons un ensemble des technologies sobres au carbone, dans le domaine de transport des marchandises, disposées à concourir pour contrer les politiques incertaines de carbone. Un modèle stochastique combinatoire, et linéaire est développé pour minimiser le coût total espéré, sous contraintes de l'abattement du carbone; limitation du budget, et la priorité attribuée pour chaque Technologie Réductrice de carbone (*Low Carbone Reduction* LCR). L'injection de chaque solution Pareto dans le modèle, et la résolution du modèle conduisent à sélectionner la configuration de la SC, la plus résiliente aux changements climatiques. Cette configuration définit non seulement le plan d'investissement optimal en LCR, mais aussi le niveau optimal d'externalisation de la logistique dans la SC.

Deuxièmement, une fois que les activités logistiques à externaliser sont stratégiquement définies et tactiquement dimensionnées, elles ont besoin d'être effectuées par des 3PL appropriées, afin de soutenir la FC à construire une SC durable et résiliente. Nous suggérons DEA-QFD / Fuzzy AHP- Conception robuste de Taguchi : Une approche intégrée & robuste, pour sélectionner les 3PL candidats les plus efficients. Les critères durables et les risques liés à l'environnement d'affaires, sont identifiés, classés et ordonnés. Le Déploiement de la Fonction Qualité (QFD) est renforcé par le Processus Hiérarchique Analytique (AHP), et par la logique floue pour déterminer avec consistance l'importance relative de chaque facteur de décision, et ce, conformément aux besoins logistiques réels, et stratégies d'affaires de la FC. L'Analyse d'Enveloppement des Données (DEA) *Data Envelopment Analysis* conduit à limiter la liste des candidats, uniquement à ceux d'efficiences comparables, et donc excluant tout candidat moins efficient. La technique de conception robuste Taguchi permet de réaliser un plan d'expérience qui détermine un candidat idéal nommé 'optimum de Taguchi' ; un Benchmark pour comparer les 3PLs candidats. Par suite, le 3PL le plus efficient est celui le plus proche de cet optimum.

Nous conduisons actuellement une étude de cas d'une entreprise qui fabrique et commercialise les fours à micro-ondes pour valider la modélisation stochastique en deux étapes. Certains aspects concernant l’application de l’approche sont reportés. Enfin, un exemple de sélection d’un 3PL durable pour s’occuper de la logistique inverse est fourni, pour démontrer l'applicabilité de l'approche intégrée & robuste, et montrer sa puissance par rapport aux approches populaires de sélection.

Abstract

The Third-Party Logistics service providers (3PLs) have the potentialities to activate sustainable practices between different partners of a Supply Chain (SC). There exists an optimal level of integrating 3PLs as suppliers of a Focal Company within the SC, to expect for high operational performances. This level leads to distinguish all the logistics activities to outsource from those to perform in-house. Once the outsourced logistics activities are strategically identified, and tactically dimensioned, they need to be performed by appropriate 3PLs to sustain economic, social and environmental performances of the SC. The present thesis develops a holistic approach to design a sustainable supply chain integrating 3PLs, in the context of business and carbon policy uncertainties.

First, a two-stage stochastic modelling approach is suggested to optimize both the level of 3PL integration, and of Low Carbon Reduction LCR investment within a climate change resilient SC. Our SC is structured to capture three main SC management issues of the Focal Company FC (e.g. The manufacturer) : Security of Supplies; Distribution Segmentation; and Extended Producer Responsibility. The first-stage of the modelling approach suggests a stochastic plan based scenarios capturing business uncertainties, and proposes a two-objective, multi-period, and multi-product programming model, for minimizing simultaneously, the expected logistics total cost, and the Green House Gas GHG emissions of the whole SC. The run of the model by means of a suggested Epsilon-constraint algorithm leads to a set of Pareto optimal decarbonized SC configurations, before any LCR investment. Each one of these configurations distinguishes the logistics activities to be outsourced, from those to be performed in-house. The second-stage of the modelling approach helps the decision makers to select the best Pareto optimal SC configuration. The concept of internal carbon price is used to establish a stochastic plan of carbon price in the context of a voluntary carbon disclosure regime, and we propose a set of LCR technologies in the freight transportation domain ready to compete for counteracting the uncertain carbon policies. A combinatory model is developed to minimize the total expected cost, under the constraints of; carbon abatement, budget limitation, and LCR investment priorities. The injection of each Pareto optimal solution in the model, and the resolution lead to select the most efficient

climate resilient SC configuration, which defines not only the optimal plan of LCR investment, but the optimal level of logistics outsourcing within the SC as well.

Secondly, once the outsourced logistics are strategically defined they need to be performed by appropriate 3PLs for supporting the FC to build a Sustainable SC. We suggest the DEA-QFD/Fuzzy AHP-Taguchi Robust Design: a robust integrated selection approach to select the most efficient 3PL candidates.
Sustainable criteria, and risks related to business environment are identified, categorized, and ordered. Quality Function Deployment (QFD) is reinforced by Analytic Hierarchic Process (AHP), and Fuzzy logic, to consistently determine the relative importance of each decision factor according to the real logistics needs, and business strategies of the FC. Data Envelopment Analysis leads to shorten the list of candidates to only those of comparative efficiencies. The Taguchi Robust Design technique allows to perform a plan of experiment, for determining an ideal candidate named 'optimum of Taguchi'. This benchmark is used to compare the remainder 3Pls candidates, and the most efficient 3PL is the closest one to this optimum.

We are currently conducting a case study of a company that manufactures and markets microwave ovens for validating the two-stage stochastic approach, and certain aspects of its implementation are provided. Finally, an example of selecting a sustainable 3PL, to handle reverse logistics is given for demonstrating the applicability of the integrated & robust approach, and showing its power compared to popular selection approaches.

Keywords:

- Third Party Logistics;
- Green Supply Chain design;
- Stochastic Multi-Objective Optimization;
- Carbon Pricing;
- Taguchi Robust Design.

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Preface

This thesis under joint supervision has been realized under the co-direction of **Pr Daoud Ait-Kadi**; Professor at the Mechanical Engineering Department of Université Laval-Canada, and **Pr Nidhal Rezg**; Professor at Université Lorraine-France.

It has been prepared as an article insertion thesis. The activities related to this thesis have been carried out at the **FiMIS** Laboratory of **Université Laval**, which is affiliated to **CIRRELT**; the "Centre Inter-universitaire de Recherche sur les Réseaux d'Entreprise, la Logistique et le Transport", and at the **LGIPM** of **Metz**, which is affiliated to "École doctorale **IAEME:** Informatique, Automatique, Électronique & Électrotechnique; Mathématiques" of **Université Lorraine**. The thesis includes three articles, co-authored by Pr. Daoud Ait-Kadi, and Pr Nidhal Rezg. The third article was either co-authored by **Dr Aicha Aguezzoul**, from LGIPM-Metz.

In all the presented articles, I acted as the principal researcher, and all the articles of the thesis have been submitted to the **International Journal of Production Economics IJPE**, in the following order:

- The first article entitled: "**Integrating Logistics Outsourcing Decisions in a Green Supply Chain Design: A Stochastic, Multi Objective, Multi period, & Multi product Programming Model**" is accepted for publication by IJPE; 182 (2016), 165-184, and available online at 31-AUG-2016; http://dx.doi.org/10.1016/j.ijpe.2016.08.031.
- The third article entitled: " **Third Party Logistics Providers Selection in the Context of Sustainable Supply Chains: A Robust Integrated Approach** ", is in process of review by the journal IJPE, since August 2016; and
- The second article entitled: " **Internal Carbon Price Impact on Low Carbon Reduction Investment, and Logistics Outsourcing Decisions in a Green Supply Chain Design: A Two-**

Stage Stochastic Modelling Approach " has been submitted to the journal IJPE, on August 2016, and accepted with some revisions.

As a doctorate student representing the two laboratories CIRRELT & LGIPM, I have participated to two academic events, by submitting two papers in relation with the subject of the thesis:

- 11e Congrès International de Génie Industriel **- CIGI 2015**-Quebec city, with the paper entitled : "**Sélection d'un Prestataire Logistique Durable : Un modèle basé sur QFD-Fuzzy AHP & Plan orthogonal de Taguchi** », 26-28 octobre 2015 ; available on line at : http://www.simagi.polymtl.ca/congresgi/cigi2015/Articles/CIGI_2015_submission_7.pdf
- 8th IFAC Conference on Manufacturing Modelling, Management and Control MIM 2016-Troyes city, with the paper entitled: " **Incorporating Design for Environment into Product Development Process: An Integrated Approach**", IFAC-Papers On Line**,** Volume 49, Issue 12, 2016, Pages 1460–1465; 28—30 June 2016, available at: http://dx.doi.org/10.1016/j.ifacol.2016.07.777

Dedications

I dedicate my dissertation work to my:

- *Beloved parents* ***Rkia Khoali Bent Mohammed****, &* ***Sidi Lmouloudi Ben Lhoussaine***;
- *Dear wife* ***Atika El Mais Bent Slimane****, dear son* ***Oussama****, and dear daughters* ***Wissal*** *&* ***Soukaina***;
- *Dear brothers & sisters* ***Noreddine****,* ***Abdessamad****,* ***Hassan Khoali****,* ***Rabia****,* ***Amina****, &* ***Khadija Khoali*** ; and
- *Unforgettable friends* ***Hammou Boukebbou****,* ***Mohammed Similla****, &* ***Hakim Boutahiri***.

Thank you so much for your precious supports, & your noble feelings.

رب اشرح لي صدري ويسر لي أمري واحلل عقدة من لساني يفقهوا قولي

صدق الله العظيم

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I would like to warmly thank the distinguished members of the jury: Pr **Sophie D'Amours** from Université Laval of Québec, as the internal reviewer; Pr **Nathalie Sauer** from Paul Verlaine University of Metz, as the internal reviewer, Pr **Farouk Yalaoui** from Université de Technologie de Troyes-France, as the external reviewer; and Pr **Claire Deschênes** from Université Laval of Québec, as the president of jury, for agreeing to assess this work.

I like to thank Dr. **Aicha Aguezzoul**, who is an associate professor in Lorraine University, and a research member of LGPM-Metz, for her important support to develop the main question of the third article concerning the Third-Party Logistics provider selection problem.

I appreciate the relevant advises, and constructive criticism that I have received, in my doctoral examinations, namely from Pr. **Georges Abdul nour** of Université Trois-Rivières; Pr. **Salah Ouali** of the Polytechnique Montréal; and Pr. **Bernard Lamond**; Pr. **Mounia Rekik** & Pr. **Adnène Hajji** of Université Laval.

My deepest appreciation is extended to Pr. **Sofiene Dellagi** of LGIPM-Metz; Dr. **Samira Keivanpour**; Dr. **Mohammed -Larbi Rebaiaia**; Dr. **Naji Bericha;** and Mme **Samira Touhami** a Ph.D. Candidate of Université Laval for their kind, and important exchanges.

Finally, I want to mention well some events, that have marked so much my Ph.D. student life: "Doctoriales de Lorraine 2013" in Ventron-Vosges; "CIGI-2015'' & "Université d'automne 2015 de l'institut EDS" in Qubec city; "Mathématiques au service de l'environnement-11eme edition des 24 heures de Sciences-2016" in

Montreal; and “IFAC/MIM-2016’’ in Troyes-city, and MITACs programs-Canada. Thank you so much Pr. **Daoud Ail-Kadi** & Pr. **Nidhal Rezg**, for these very important opportunities.

Abbreviations

3PL (s)	Third Party Logistics Provider (s)
AHP	Analytic Hierarchic Process
ANP	Analytic Network Process
ATRI	American Transportation Research Institute
CDP	Carbon Disclosure Project
COP21	The 2015 United Nations Climate Change Conference (21th)
cu. Ft	cubic foot
eGRID	*e*missions & *G*eneration *R*esource *I*ntegrated *D*atabase
ELECTRE	ÉLimination Et Choix Traduisant la RÉalité
EPA	U.S. Environmental Protection Agency
ETS	Emissions Trading Scheme
EU	European Union
DEA	Data Envelopment Analysis
DMU (s)	Decision Making Unit (s)
FC	Focal manufacturing Company within the Supply Chain
GHG	Green House Gas
GRI	Global Reporting Initiative
HDV	Heavy Duty Vehicle
HoQ	House of Quality
INDC	Intended Nationally Determined Contributions
ISO	International Organization of Standardization
ITR	Inventory Turnover Rate
% LCR	Percent of Low Carbon Reduction

LT	Truck Load carrier
LTL	Less Than Truck Load carrier
MDV	Medium Duty Vehicles
MIT	Massachusetts Institute of Technology
ONG	Non-Governmental Organizations
PROMETHEE	Preference Ranking Organization METHod for Enrichment Evaluations
QFD	Quality Function Deployment
SC (s)	Supply Chain (s)
TEU	Twenty-foot Equivalent Unit container (20x8x8 feet)
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
UNFCCC	United Nations Framework Convention on Climate Change
US.	United States of America
WBCSD	World Business Council for Sustainable Development
WRI	World Resources Institute

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Chapter 4

Chapter 1:

General Introduction

1.1 Context

Supply Chains (SCs) involve Suppliers, Manufacturers, Distributors & Retailers, Consumers, and other partners such as Third-Party Logistics providers (3PLs) and Recyclers. Each link in a SC while adding value to the products, contributes to the natural environment degradation; particularly by the climate change problem involvement (Dasaklis & Pappis, 2013), and to the social image formation of the whole SC. Huang *et al.* (2009) have reported that more than 75% of the Green House Gas (GHG) emissions in many industry sectors come from their SCs. Upstream GHG emissions are, on average, more than twice those of a Focal Company's operational emissions, which makes it critical to build climate resilience into SCs (CDP & BSR, 2016). While the escalating flow of information has given rise to stories about companies' irresponsible social practices, such as violation of union rights, use of child labour, dangerous working conditions, race and gender discrimination, etc. Well known examples from the media are Nike, Gap, H&M, WalMart, and Mattel (Andersen & Skjoett-Larsen, 2009; Frost and Burnett, 2007). Therefore, the decisions regarding the activities performed by the mentioned actors will determine both the environmental, the social, and the economic performances of the SCs (Wang *et al.* 2011).

The appropriate integration of customers and suppliers in the SCs may help Focal Companies (FCs) within the global SCs to; design and produce green products (Ameknassi *et al.* 2016); build climate change resilient SCS, and face increased regulatory risks (CDP, 2016); improve the social corporate responsibilities (Carter & Jennings, 2002); and maintain high level of competitiveness (Jayaram & Tan, 2010). In "Sustainable" SCs, environmental and social criteria need to be fulfilled by the members to remain within the SCs, while it is expected that competitiveness would be maintained through meeting customer needs, and related economic criteria (Seuring & Müller, 2008). Nowadays, more than 8 000 businesses around the world have signed the United Nation Global Compact pledging to show good global citizenship in the areas of human rights, labor standards and environmental protection (Wharton, 2012). Media & Non-Governmental Organizations (ONG) continue to put more pressure on public & private organizations to control their outsourcing practices, while considering all the aspects of sustainability in their call for tenders (Sullivan & Ngwenyama, 2005).

However, according to Das *et al.* (2006), the full suppliers' integration within the SC is intriguing:

On the one hand, supplier integration can lead to enhanced business performance through economies of scale and scope (Jayaram & Tan, 2010).

On the other hand, interdependence may create rigidities, inflexibilities, and coordination issues that can affect social and environmental performance negatively (CDP & BSR, 2016; Wolf & Seuring, 2010).

To conciliate the two contradictory states, Das *et al.* (2006) have theorized the existence of an optimal level of suppliers' integration within the global SC, that results in high economic, environmental, and social performances.

In the present thesis, we consider the integration of the Third-Party logistics service providers (3PLs) as a strategic issue in sustainable SC management, and we ask two main questions:

- ***To achieve optimal economic and environmental SC performances, to what extent 3PLs should be integrated in a SC to build a climate change resilient SC, in the context of business, and carbon policy uncertainties?***
- ***Once the optimal level of 3PL integration is known, how the Focal Company (FC) within the green SC can select the most efficient 3PLs for its Inbound, Outbound, and Reverse logistics activities being outsourced, in order to build a sustainable SC?***

1.2 Problem description

The thesis subject falls into the intersection of three streams of research: 1) SC network design problem; 2) Carbon policies design problem; and 3) 3PL selection problem.

- Concerning the first stream of research, the SC network design consists of combining SC management paradigms with Operational Research models to optimize one or many objectives assigned to the SC. It determines a portfolio of configuration parameters including the number, location, capacity, and type of various facilities in the network (Wang *et al.* 2011).

Many efforts have been made on the design of SC networks, and the suggested models in the literature can be classified according to their degrees of:

a) Scope (Forward; Reverse; and Closed-loop SC),

b) Realism (Horizon of time; number and type of products; security of supplies; customer segmentation…),

c) Complexity (Mono or Multi-objective functions; robust-stochastic or deterministic parameters; linear or non-linear programming models) not in the sense of Complexity theory; and

d) Resolution (Classical methods such as parametrized objectives sum & epsilon-constraint method; and Non-classical methods such as evolutionary algorithms)

Ultimately, very few programming models have succeeded to capture the four aspects together, with high degrees. So, many of the models are so far from the industrial reality, or still suggest suboptimal solutions. In their robust model, Gao & Ryan, (2014), highlighted the importance to integrate the logistics outsourcing decisions within the SC network design problems, to reduce business environment risks, and avoid sub-optimal SC configurations.

- Concerning the second stream of research, the Carbon policy design comprises 1) Seven Green House Gas emission GHG measurement & reporting (Montoya-Torres et al. 2015; WRI/WBCSD, 2013), 2) Carbon pricing strategies alignment (CDP, 2015; Rydge, 2015.); and 3) Available & Emerging Low Carbon reduction & Energy Efficiency approaches implementation, notably those of freight transportation (Brown D., 2010).

Depending on which one performs a business activity within the SC, the insourcing or outsourcing cost and corresponding GHG emissions should be computed correctly (Blanco & Craig, 2009). Although the 3PLs may provide incentive economic efficiencies, they seem not undertake concrete sustainable initiatives vis-à-vis the energy efficiency & GHG emissions (e.g. 20 to 30% moreover than private FC's operations), and vis-à-vis the traffic congestion (e. g. more than 17% of fuel cost, because the choice of a flexible routing network strategy, rather than a point-to-point strategy for picking, and deliveries) (Evangelistia *et al.* 2011; Blanco & Craig, 2009; Webster & Mitra, 2007; Facanha & Horvath, 2005). So, it is worth to use established models of cost and GHG computation, rather than using gross values from the literature, for building credible & reliable data base.

Global SCs can experience two regimes of carbon disclosure (CDP, 2015):

a) Mandatory carbon disclosure regime (e.g. EU Emissions Trading Scheme ETS; US Environmental Protection Agency; California-Quebec Cap and Trade; Australia ETS; South Africa Carbon tax), in which the carbon price may be forecasted for a short horizon of time following the carbon policy in effect; and

b) Voluntary carbon disclosure regimes (e.g. Carbon Disclosure Project CDP, and Global Reporting Initiative GRI) in which SC may experiencing uncertain carbon policies to be counteracted by Low Carbon Reduction investments.

Freight transportation is the most onerous and pollutant logistics activity, and available and emerging low carbon technologies should be considered in terms of their costs, payback times, and expected Low Carbon Reduction rates to counteract the carbon policies, and optimize their investment planning. (See the rapport of the Committee to assess Fuel Economy Technologies for Medium-and-Heavy Duty Vehicles, in Brown (2010)).

Concerning the third stream of research; the problem of Third Party Logistics (3PL) selection. Once the logistics activity to be outsourced is justified financially, and strategically, it is worth to select an appropriate 3PL to deal with it (Hätönen & Eriksson, 2009). Sink & Langley (1997) had provided a conceptual model of the 3PL outsourcing process with five stages: 1) Identify the need to outsource logistics; 2) develop feasible alternatives; 3) evaluate and select the 3PL supplier; 4) implement service; and 5) ongoing service assessment. The 3PL selection is a multi-criteria problem, in which most of the selection criteria are intangible and conflictual (Aguezzoul, 2014). Recent works of 3PL selection have suggested many selection criteria, and have adopted a variety of evaluation methods. Very few works have integrated social and environmental criteria in their decisional structures (Winter & Lasch, 2016; Wittstruck & Teuteberg, 2011; Presley *et al.* 2007), and the most popular evaluation methods are Data Envelopment Analysis (DEA), and Analytic Hierarchic process (AHP) based methods (Ho *et al.* 2010).

In the context of sustainable SCs, a relevant question can be raised:

- ***Do we seek for selecting the most effective 3PL candidate, or the most efficient one?***

According to Ho *et al.* (2010), the decision makers have to consider the resource limitations (e.g., budget of buyer and capacities of suppliers), when looking for an *efficient* supplier. Doing so, they will prevent oversizing the level of real needs, and therefore avoid incremental costs of idle resources and capabilities.

So, developing a sound 3PL selection decision making, in the context of sustainable SCs will depend on the ability to identify and parametrize the most relevant factors, that influence the sustainability of the logistics process being outsourced. It will depend also on the ability to evaluate the process efficiency, which is subjected to inherent disturbances affecting the process within the SC.

The present thesis attempts to answer to the two main questions posed above, by suggesting a holistic approach to capture, in the context of business and regulation uncertainties both: 1) the main issues of SC management such as security of supplies, heterogeneous requirements of customers, and the Extended Producer Responsibility of the Focal Company within the SC; 2) the climate change issue, and related regulatory risks; and 3) the sustainable criteria, and risk factors to select an efficient 3PL for a determined logistics activity to be outsourced .

1.3 Objectives & Structure of thesis

Three objectives are assigned to this thesis, and each one constitutes a contribution addressed respectively in the chapter **2**, **3**, and **4**.

The first contribution is the development of a stochastic multi-objective, multi-period, and multi-product programming model. The model integrates logistics outsourcing decisions in a green SC network design problem, before any investment in Low carbon reduction technology. The objectives are minimizing both the total expected logistics costs, and minimizing the total expected GHG emissions of the closed-loop SC, which considers the three supply chain management issues: 1) Security of supplies; 2) Distribution segmentation;

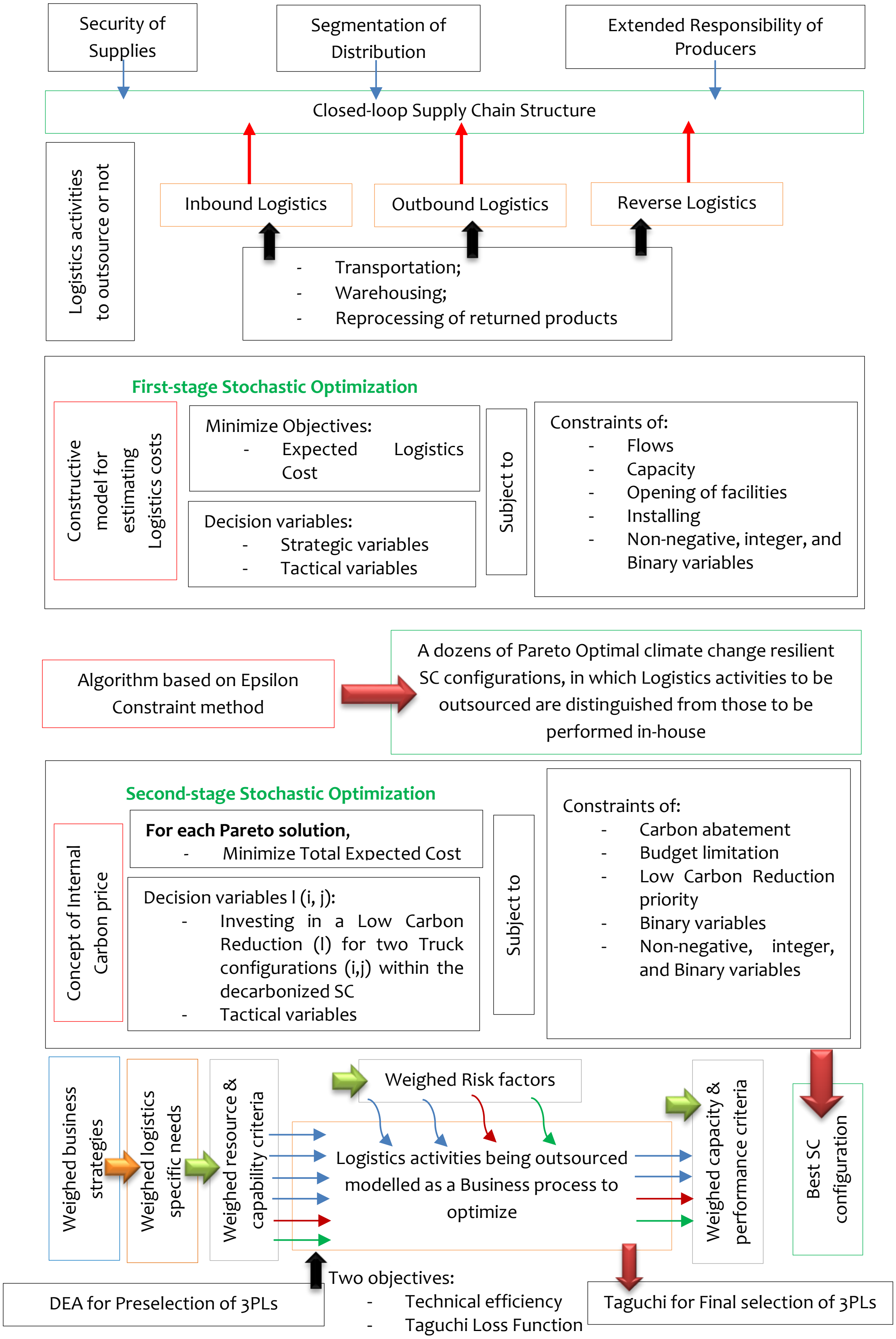
and 3) Extended Producer Responsibility. To implement the programming model, we suggest an algorithm based on Epsilon-Constraint method, which leads to a set of Pareto optimal green SC configurations, in which logistics activities to outsource are distinguished from those to perform in-home, warehouses & hybrid warehouses to be open are determined, and the quantities of products to move between nodes are known, at any period and for each scenario.

To help decision makers selecting the best green SC configuration, the second contribution is the development of a stochastic combinatory model, introducing the concept of internal carbon price to optimize the low carbon reduction investment. The objective is to minimize the total cost for each Pareto optimal SC configuration, under constraints of; 1) Carbon abatement, 2) Budget limitation, and 3) Low carbon reduction technology priority. The green SC configuration with the minimum of minimum cost is the best one. So, not only the optimal investment of Low Carbon technologies to counter act the uncertain carbon policy is determined, by the optimal level of 3PL is determined as well.

Once the SC is decarbonized, and the Low Carbon Reduction investment is optimized to counteract effectively the carbon policies. The identified logistics activities to be outsourced should performed by appropriate 3PLs. To build a sustainable SC, the FC must select and support its suppliers to implement effective social and environmental practices within the SC. The third contribution is the suggestion of a robust integrated approach to assist the FC selecting the most efficient 3PL, in the context of a sustainable SC.

The remainder of the thesis is as follows: Chapter 1, 2, and 3 are consecutively addressed, and the general conclusion, in which we notify main contributions, and limitations is drawn. Hereunder, we provide a synopsis illustrating the structure of the thesis:

Synopsis:



Security of Supplies
Segmentation of Distribution
Extended Responsibility of Producers
Closed-loop Supply Chain Structure
Logistics activities to outsource or not
Inbound Logistics
Outbound Logistics
Reverse Logistics
- Transportation;
- Warehousing;
- Reprocessing of returned products
First-stage Stochastic Optimization
Constructive model for estimating Logistics costs
Minimize Objectives:
- Expected Logistics Cost
Decision variables:
- Strategic variables
- Tactical variables
Subject to
Constraints of:
- Flows
- Capacity
- Opening of facilities
- Installing
- Non-negative, integer, and Binary variables
Algorithm based on Epsilon Constraint method
A dozens of Pareto Optimal climate change resilient SC configurations, in which Logistics activities to be outsourced are distinguished from those to be performed in-house
Second-stage Stochastic Optimization
Concept of Internal Carbon price
For each Pareto solution,
- Minimize Total Expected Cost
Decision variables l (i, j):
- Investing in a Low Carbon Reduction (l) for two Truck configurations (i,j) within the decarbonized SC
- Tactical variables
Subject to
Constraints of:
- Carbon abatement
- Budget limitation
- Low Carbon Reduction priority
- Binary variables
- Non-negative, integer, and Binary variables
Weighed business strategies
Weighed logistics specific needs
Weighed resource & capability criteria
Weighed Risk factors
Logistics activities being outsourced modelled as a Business process to optimize
Weighed capacity & performance criteria
Best SC configuration
Two objectives:
- Technical efficiency
- Taguchi Loss Function
DEA for Preselection of 3PLs
Taguchi for Final selection of 3PLs

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Chapter 2:

Integrating Logistics Outsourcing Decisions in a Green Supply Chain Design:

A Stochastic Multi Objective Multi Period Multi Product Programming Model

Highlights:

- Integration of some critical Supply Chain Management issues in the green supply chain design;
- Suggestion of constructive models to roughly estimate logistics costs and carbon emissions;
- An example of stochastic plan is provided to capture different business uncertainties;
- An Epsilon-constraint algorithm leads to a set of Pareto optimal green configurations, with optimal levels of logistics outsourcing.

Résumé

Ce chapitre développe un modèle de programmation, qui combine les décisions d'externalisation de la logistique avec certaines questions de planification stratégique du *Supply Chain*, telles que la sécurité des approvisionnements, la segmentation de la clientèle, et la responsabilité élargie des producteurs.

Le but est de minimiser à la fois le coût espéré de la logistique et les émissions de Gaz à effet de Serre (GES) d'un réseau logistique, dans un contexte d'affaires incertain. Tout d'abord, nous définissons la structure générale d'une chaîne logistique en boucle fermée. Deuxièmement, nous fournissons des modèles constructifs pour estimer grossièrement les coûts logistiques et les émissions de GES correspondantes, aussi bien pour effectuer en privé les activités logistiques, que de les externaliser. Troisièmement, nous établissons un plan stochastique basé sur une approche des scénarios, pour capturer l'incertitude de ; la demande ; les capacités d'installations ; la quantité et la qualité des retours de produits utilisés ; ainsi que les coûts de transport, d'entreposage, et de retraitement. Quatrièmement, nous proposons un modèle de programmation, et un algorithme basé sur la méthode *Epsilon-contraint* pour le résoudre.

Le résultat est l'aboutissement à un ensemble de configurations 'vertes' optimales et non dominantes, de la chaîne logistique. Ces configurations fournissent aux décideurs le niveau optimal d'intégration des sous-traitants logistiques, au sein d'une chaîne logistique dé-carbonisée, avant tout futur investissement sobre au carbone.

Abstract

This chapter develops a programming model, which combines logistics outsourcing decisions with some strategic Supply Chains' planning issues, such as the Security of supplies, the customer Segmentation, and the Extended Producer Responsibility. The purpose is to minimize both the expected logistics cost and the Green House Gas (GHG) emissions of the Supply Chain (SC) network, in the context of business environment uncertainty. First, we define a general structure of the closed-loop SC. Second, we provide constructive models to roughly estimate the insourcing and outsourcing logistics costs, and their corresponding GHG emissions. Third, we establish a stochastic plan based on a scenarios approach to capture the uncertainty od demand, capacity of facilities, quantity and quality of returns of used products, and the transportation, warehousing, and reprocessing costs. Fourth, we suggest a programming model, and an algorithm based on the Epsilon-constraint method to solve it. The result is a set of optimal non-dominant green SC configurations, which provide the decision' makers with optimal levels of logistics outsourcing integration within a decarbonized Supply Chain, before any further low-carbon investment.

Keywords:

- Supply Chain Integration
- Third-Party Logistics
- Logistics costs
- Green House Gas emissions
- Stochastic multi-objective optimization.

2.1. Introduction

Supply Chains (SCs) involve Suppliers, Manufacturers, Distributors & Retailers, Consumers, and other partners such as Third-Party Logistics providers (3PLs) and Recyclers. Each link in a SC while adding value to the products, contributes to degradation of the natural environment; particularly by the climate change problem involvement (Dasaklis & Pappis, 2013). Therefore, the decisions regarding the activities performed by the mentioned actors will determine both the environmental and the economic performances of the SCs (Wang *et al.* 2011):

Concerning the environmental performance, Huang *et al.* (2009) have reported that more than 75% of the Green House Gases (GHG) emissions of many industry sectors come from their SCs. So, reducing those indirect GHG emissions may be more cost-effective for an industrial company, than reducing its direct GHG emissions (Montoya-Torres *et al.* 2015). In Browne et al. (2009), the World Economic Forum suggests thirteen effective strategies to decarbonize the SCs, and among the most effective ones: Improving the network logistics planning, through global optimization.

Concerning the economic performance, and according to 19th, and 17th annual 3PL studies of Langley & Cap Gemini (2015; 2013) the total of logistics expenditure of the eight largest industry sectors in the world is between 12% and 15% of the sale revenue, and about 40% of the global logistics activities is outsourced to the 3PLs. The most important logistics activities outsourced are freight transportation, warehousing, and reverse logistics. According to the authors, the logistics outsourcing, as a flexible strategy can reduce logistics costs by 10%, logistics fixed-asset by 15%, and inventory by 25%, if it is well defined by the focal company (FC). So, considering the possibility of 3PL integration within the SC is of great importance to minimize the costs, and reduce the business risks (Jayaram & Tan, 2010).

However, the 3PLs seem not undertake concrete sustainable initiatives vis-à-vis the energy efficiency, the GHG emissions, and the traffic congestion (Evangelistia et al. 2011; Blanco & Craig, 2009). For instance, the 3PLs tend to use a flexible routing network strategy, rather than a point-to-point strategy, to consolidate the freight of different customers (Hesse & Rodrigue, 2004). This can generate a lot of stops between different origins and destinations, hardly provoke traffic congestion, increase relatively the distances, and therefore raise the GHG emissions.

So, considering the potential economic efficiency of 3PLs, and their presumed environmental inefficiency, two main questions are raised in this paper:

- Given that the freight transportation, warehousing, and reprocessing of reused product for the purpose of remanufacturing are not the FC's core activities, one of the most important decisions to be taken is whether or not outsourcing totally or partially such logistics activities to 3PLs, in the context of a green SC.
- How does the optimality of GHG emissions of logistics activities, and corresponding logistics costs affect the configurations of a closed-loop SC network integrating 3PLs, in the context of business uncertainty?

The main contribution of the present paper is the suggestion of a more realistic programming model, which integrates logistics outsourcing decision within the closed-loop SC design network problem, in the context of business uncertainty. The model captures three important issues of the SC management: 1) The security of supplies, by considering the portfolio model of supplies (Kraljic, 1983); 2) the segmentation of market, for meeting the heterogeneous requirements of customers (Lee, 2002); and 3) the Extended Producer Responsibility for managing effectively the End of Life phase of products (Lindhqvist, 2000).

The objective is to minimize both the expected total logistics cost (e.g. Freight transportation; Warehousing; and Processing returns of used products), and the corresponding expected total GHG emissions, under the constraints of: a) flow conservation, b) fleet & facilities capacities, c) opening of facilities, and d) installing hybrid facilities, which may be leased and operated by FC, or owned and operated by 3PLs.

- We provide three constructive models to make rough estimate of logistics costs and GHG emissions of logistics operations to be insourced or outsourced;
- We suggest a stochastic plan, based on a scenarios approach (Pishvaee *et al.* 2008) to capture the uncertainty of demand, quantity and quality of returned products, and the variable costs of logistics operations; and

- We suggest an algorithm based on Epsilon- Constraint method (Mavrotas, 2009), to solve the stochastic bi-objective, multi product, multi-period, and multi-echelon programming problem;

The solutions represent a set of non-dominant green SC configurations; which distinguish the logistics activities that should be performed in-house from those that should be outsourced.

The remainder of this paper is organized as follows. In section 2, we provide a literature overview on the 3PL' integration within SCs; and on the Green SC network design problem. In section 3, we define the general structure of a closed-loop SC, and provide three constructive models to roughly estimate the fixed and variable costs, and the fixed and variable GHG emissions of different logistics operations. In section 4, we present the modelling and solving approaches of the closed-loop SC design problem. Then, we discuss some managerial insights, which can be deducted from the implementation of an example of the model. Finally, in the section 5 we draw the conclusion.

2.2. Literature review

2.2.1. Logistics outsourcing

Third-Party logistics (3PL), is a company that works with shippers to manage their logistics operations. According to Bask (2001), it may offer three distinguished services:

- Routine services which include all types of basic transportation and warehousing;
- Standard services which contain some easy customized operations like special transportation where products need to be cooled, heated or moved in tanker trucks; and
- Customized services which consist of different postponement services like light assembly of product, packing product and/or recovery, and reverse logistics operations.

In a recent survey conducted by Langley & Cap Gemini (2015), even though 40% of the global logistics is outsourced, systematically, every year about 30% of 3PL' users decide to return back to in-source some or all of their logistics needs. Ordoobadi (2010) noted that the integration of 3PL in a SC is a strategic decision, and any inappropriate choice of the logistics activity to outsource or any inadequate selection of 3PL has undesirable consequence on the performance of the Focal Company FC.

Logistics outsourcing decisions have been investigated by asking the key questions; Why? What? Where? Who? How? And there have been many studies conducted on:

- "Why?" outsourcing logistics (Anderson *et al*. 2011; Hsiao *et al*. 2010);
- "What?" logistics activities should be outsourced (Serrato *et al.* 2007; Savaskan *et al.* 2004),
- "Where?" outsourcing logistics (Bunyaratavej *et al.* 2007; Graf & Mudambi, 2005)
- "Who?" is the most effective 3PL to select for performing a logistics activity (Ordoobadi, 2010; Hamdan & Rogers, 2008);
- "How?" to manage the relationship between outsourcing companies and 3PLs (Yang & Zhao, 2016; Flynn *et al.* 2010)

However, the key question:

- "To which extent?" logistics operations should be outsourced remains the least addressed issue within the strategic management research (Gao & Ryan, 2014; Hätönen & Eriksson , 2009; Leung *et al.* 2002).

According to Das *et al.* (2006), the answer to the question presumes the existence of an optimal level of 3PL integration, which must be satisfied, so that logistics outsourcing can effectively contribute to the overall performance of the SC.

Thus, the present paper is a contribution to enrich the logistics literature, by integrating logistics outsourcing decisions in green SC network design problems. The optimal integration of 3PLs can be achieved by a programming model that provides global optimal SC configurations, in which outsourced freight transportation, warehousing, and reprocessing of returned products activities are distinguished from the insourced ones, while considering the other green SC management issues.

2.2.2. Green SC network design problem

The SC network design consists of combining SC management paradigms with Operational Research models to optimize one or many objectives assigned to the SC. It determines a portfolio of configuration parameters including the number, location, capacity, and type of various facilities in the network (Wang *et al.* 2011). ‘‘Green’’ SC management refers to the way in which organizational innovations and policies in SC management may be considered in the context of the sustainable environment, and it involves different multiple objectives of social, economic and environmental sustainability (Allaoui & Goncalves, 2013).

Many efforts have been made on the design of Green SC networks. The suggested models in the literature can be classified according to four degrees of:

1) Scope; 2) Realism; 3) Complexity; and 4) Resolution:

- Scope: Forward (Nouira *et al.* 2016), reverse logistics (Demirel, & Gökçen, 2008), and closed-loop SC networks (Pishvaee *et al.* 2010)
- Realism: Products/Customer segmentation (Salema *et al.* 2006); Time horizon (El-Sayed *et al.* 2010), Regulation (Hoen *et al.* 2014; Fareeduddin et *al.* 2015); Supply security (Mirzapour Al-e-hashem *et al.* 2013); and Outsourcing (Min & Ko, 2008).
- Complexity: Non-linear/Linear model programming (Wang *et al.* 2011); Multi-objective (Ramezani *et al.* 2013); Stochastic (Pishvaee *et al.* 2009); and Robust (Gao & Ryan, 2014).
- Resolution: Classical methods such as parametrized objectives sum (Sazvar *et al.* 2014), and epsilon-constraint method (Wang *et al.* 2011); and Non classical methods such as evolutionary algorithms (Aravendan & Panneerselvam, 2015)

Ultimately, very few programming models have been proposed with high degrees of: 1) the scope (e.g. limited echelons, forward or reverse logistics); 2) realism (e.g. some of SC management are only considered, one period in the horizon time); 3) complexity (e. g. one objective to optimize, deterministic or some of stochastic parameters); and 4) resolution (simplified examples to run the programming models). For instance, many models are so far from the reality by neglecting or mitigating the degree of those aspects. In their robust model, Gao & Ryan, (2014), highlighted the importance to integrate the logistics outsourcing decisions within the SC network design problems, to reduce business environment risks, and avoid sub-optimal SC configurations.

In this paper we try to capture the potential drawbacks (e.g. low degrees of the scope, realism, complexity, and resolution) that repel the SC design models from the reality, and present a Bi-objective, stochastic, multi-period, multi-product, multi-echelon programming model, which integrates transportation, warehousing, and reprocessing of returned products outsourcing decisions. The non-linear programming model has two objectives: minimizing both the expected logistics cost, and the expected GHG emissions, in the context of business uncertainty. It considers the Kraljic Portfolio Purchasing frame (Kraljic, 1983) for maximizing supply security and reducing costs, considers the product/customer segmentation (Lee, 2002) for meeting the heterogeneous requirements, and considers the Extended Producer Responsibility for managing effectively the End of Life phase of products (Lindhqvist, 2000).

Hereunder, we define the closed-loop SC design problem, provide the SC designers with constructive models to roughly estimate different costs of Insourced/Outsourced freight transportation, warehousing, and reprocessing of returned products, and the corresponding GHG emissions. Then, we present the modelling and solving approaches of the SC network design problem.

2.3. Problem definition

2.3.1. General structure of the Closed-loop SC

The SC considered in this paper is an integrated forward/reverse logistics network, which organizes the upstream and downstream into specific subnetworks, according to the characteristics of supplies, the ownership of facilities, and the segmentation of deliveries and pickups. It is structured into 6 echelons:

- *Echelon1*: Referring to the Bill of Materials (BOM), raw materials, components, packages, and accessories required to manufacture different products are categorized into four types of supplies ($s \in S$). These supplies are managed with distinctive procurement strategies, to minimize cost and maximize the supply security. According to Kraljic (1983), we distinguish: Noncritical supplies (*s*1), which may be put together in large quantities, to optimize the order volume and inventory; Leverage supplies (*s*2), which require competitive bidding and short term contracts to manage costs and material flow; Bottleneck supplies (*s*3), which require keeping safety stock, and managing costs; and Strategic supplies (*s*4), which require maintaining mutual trust, and open exchange of information to ensure long-term availability. In this paper, the potential suppliers ($n \in N$) of each category of supplies (*s*) are constrained to not exceed a maximum quota λ_S .
- *Echelon 2:* the FC operates a set M of plants (indexed $m \in M$), with assembly-type operations. The supplies $s \in S$ are transformed into three finished products ($p \in P$): Standard (p=1), Innovative (p=2), and Hybrid (p=3). According to Vonderembse *et al.* (2006), p=1 are characterized by a steady demand, and the customer contact tends to be periodic, rather than continuous; p=2 are designed to be adaptable to changing customers' requirements. They necessitate a close and continuous customer contact, and have uncertain demands; and p=3 are complex products, which have several components. They are supposed being the major purchases made periodically by the customers. We suppose that any product ($p \in P$) is manufactured in a plant ($m \in M$), with respect to a

predetermined quota κ_{pm}, and the plants receive the recoverable products from potential reprocessing centers, with the same quota.

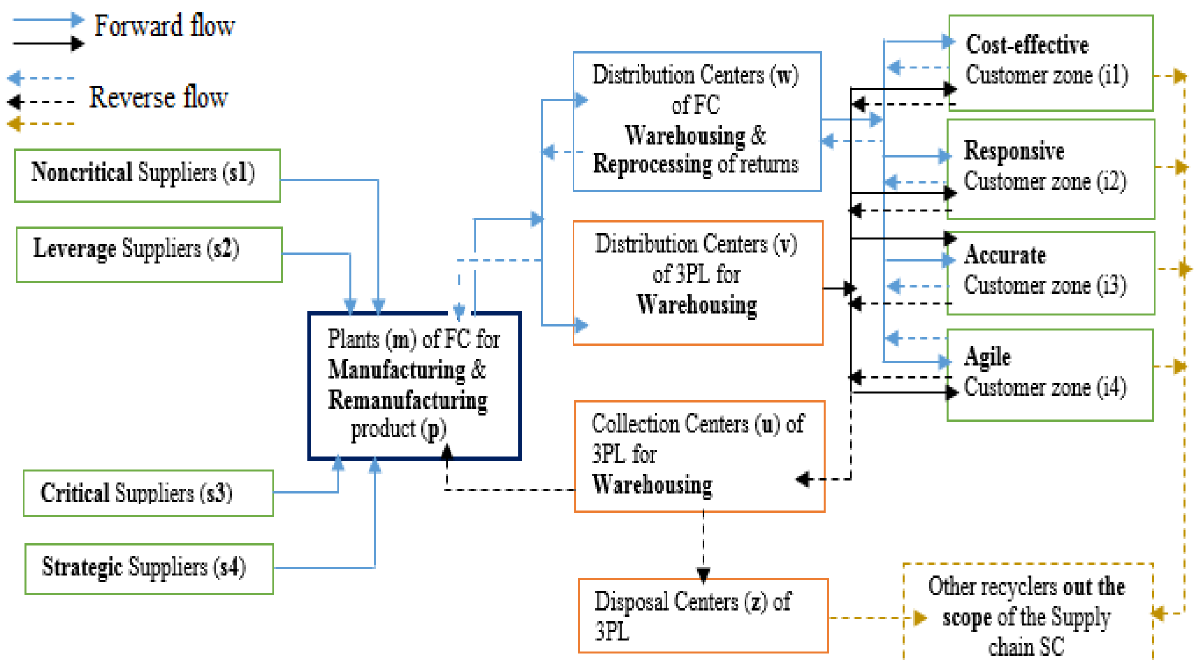
- *Echelon 3:* A set of potential warehouses W (indexed $w \in W$) managed by FC, and a set of warehouses V (indexed $v \in V$) managed by 3PLs, with known locations, and flexible annual capacities are intended to streamline the flow of products ($p \in P$), between plants($m \in M$) and customer zones $k \in K$.
- *Echelon 4:* Considering simultaneously the behavior of demands and the characteristics of customers, and according to Lee (2002), the distribution subnetwork is divided into four segments (indexed $i \in I$), to satisfy the heterogeneous customer needs ; Cost-effective segment (i=1) which aims for highest capacity utilization to create the cost efficiency in the SC; Responsive segment (i=2) which follows an aggressive make-to-order strategy to be responsive, and flexible to changing orders; Accurate segment (i=3) which strives to optimize inventories by keeping the pipeline flowing, to reduce the risk of supply shortage; and Agile segment (i=4) which pursues a combination of make-to-order and make-to- buffer stock strategies to be responsive, while reducing the risk of supply shortage. The dynamic distribution of each segment may be characterized by a specific composition of the demand, and a specific customer visiting frequency. This must have a significant effect on the Inventory Turnover Rate ITR_p of each product ($p \in P$) within the warehouses ($w \in W$) and ($v \in V$)
- *Echelon 5:* A substantial return flow of used products may result from either generous return policies of the FC, or the Extended Producer Responsibility legislation. Collection centers ($u \in U$) belonging to 3PLs, and potential hybrid warehouses ($w \in W$) managed by FC, with flexible subscribed capacities are intended receiving and reprocessing a part of the returns from the distribution segments ($i \in I$). We suppose that the recoverable products ($p \in P$) within the reprocessing centers have the same ITR .
- *Echelon 6:* A fraction eD_p of returned product ($p \in P$) is considered as an unrecoverable (scrapped) product, and has to be shipped to disposal centers (indexed $z \in Z$) belonging to 3PLs, to continue

further recycling processes by means of others recyclers (out of the scope of this SC). The rest of returned product (p ∈ P) is considered as a recoverable product, and has to be shipped to plants (m ∈ M), for the purpose of remanufacturing.

We suppose in this paper, that there is no flow between the same nodes of a given echelon of the SC. The general structure of the SC is illustrated in the figure **2.1**.

The transportation, warehousing, and reprocessing activities may be performed by either the FC, or the 3PLs, depending on the optimal configurations of the SC network.

Hereunder, we provide constructive models for computing logistics costs and corresponding GHG emissions of operating privately, or outsourcing the logistics operations.



N. B. The freight, warehousing, and reprocessing for the purpose of remanufacturing may be performed privately by the FC, or outsourced to 3PL

Fig. 2.1. The general structure of the closed-loop Supply Chain

2.3.2. Logistics costs and GHG emissions computing models

It is not so easy to compare the economic and environmental performances of the FC as a private logistics operator, and the 3PL service providers. But there are some basic assumptions that can be made, to structure logistics costs and GHG emissions that FC and 3PL may experience. We suppose that we examine the nearly identical available technologies, which are utilized in transportation, warehousing, and reprocessing of discrete non-perishable products.

The structures of the logistics cost and GHG emissions depend on the volume performed, and the asset ownership status of the facilities. According to Schniederjans *et al.* (2015), the ownership status may be as follows:

- An external company supplies the asset with a subscribed capacity, but the management remains with the FC (e.g. operating lease);
- A 3PL is contracted to supply and manage the assets (Logistics outsourcing); and
- The assets are owned by the FC, and a 3PL undertakes the management of the assets.

The present paper compares only the two first asset ownership statutes. Transportation, warehousing, and reprocessing of used products, for the purpose of remanufacturing are question of in-sourcing or outsourcing, but the disposal operation, is supposed to be outsourced, as being a special activity, which deals with recycling operations of a great volume of raw materials.

2.3.2.1 Logistics cost computing models:

Logistics cost FCCost(X) = Freight transportation cost
+ Warehousing cost
+ Reprocessing cost of returned product
+ Disposal cost

In the case of operating privately a logistics activity X, each entity of the cost may be divided into two parts: fixed cost, and variable cost.

$$\mathbf{FCCost(X) = fCost(X) + vc_X . q(X)} \quad \text{(i)}$$

fCost(X) : Annual fixed cost to perform the activity X

vc_X : Unit variable cost to perform the activity X, in terms of ($/unit of product)

Cap(X) : The maximal number of product that may be performed annually by the activity X (Subscribed capacity of X)

q(X) : The annual quantity processed by the activity X in terms of performed units of product

In the case of outsourcing the activity *X* to a 3PL, an according to Facanha & Horvath, (2005), and Webster & Mitra, (2007) the fixed cost is transformed to a variable cost, and the cost of outsourcing may be expressed as:

$$\mathbf{3PLCost(X)} = (1+\pi_X^{3PL}).(1-E_X).\left\{\frac{fCost(X)}{Cap(X)}+vc_X\right\}.q(X) \quad \text{(ii)}$$

π_X^{3PL} : The profit margin of the 3PL service provider to perform the activity X.

E_X : The efficiency of outsourcing the activity X.

$0.05 \le E_{Transport} \le 0.20$

$0.05 \le E_{Warehousing} \le 0.20$

$-0.10 \le E_{Reprocessing} \le 0.10$

Hereunder, we estimate the terms fCost(X) & vc_X of each logistics operation *X*:

- X: Freight transportation T

To determine fCostT and vc_T , three strategic issues should be addressed (Hoff *et al.* 2010; Zak *et al.* 2008): 1) Selecting the mode of transport, 2) Defining the fleet configuration (size of containers, trailers, and trucks); and 3) Sizing the fleet & optimizing transportation routes.

1) Regarding the modalities, the scope of this paper is road-based and maritime freight transportation.

2) Concerning the fleet configuration, and according with Gencer *et al.* (2006), we use the principle of first clustering around a given destination node within the network, second sizing the fleet. Land origins are categorized into clusters. For instance, suppliers are categorized into strategic, leverage, bottleneck, and critical clusters. Warehouses are categorized into warehouses belonging to FC, and warehouses belonging to 3PL. Customers are categorized into cost-effective, responsive, accurate, and agile segments, and reprocessing centers are categorized into hybrid warehouses belonging to FC, and collection centers belonging to 3PL. Each cluster is divided into inside cluster, and outside cluster, according to the geographic location, and we assign a fleet for each of them. To take economics advantages of the larger vehicles over the longer distances, we suggest the following configuration:

- If the average distance between the cluster of land origins and the land destination is $\bar{\delta} \leq 500$ miles (≈ 804.64 km), then the FC will privately operate Medium Duty Vehicles MDV (e.g. Tractor-28 feet trailer).
- Otherwise, the FC will operate Heavy Duty Vehicle HDV e.g. Tractor-53 feet trailer).

The FC should consider the strategic choice between leasing and privately managing the fleet, or outsourcing it to a LTL (*Less Than Truck Load*) carrier for the short haul, *and to a* TL (*Truck Load*) carrier for the long haul (Simchi-Levi *et al.* 2003).

When it is question to use maritime transportation, we suggest the use of 20 feet containers to load products in a ship. The maritime operations may be privately managed or let it to a 3PL.

3) Concerning the fleet sizing, determining the right number of trucks for each configuration will depend on several operational factors (Żak *et al.* 2008; McKinnon & Ge, 2006). Such as: Design of product; Vehicle load factor; Speed; Vehicle reliability; Time of loading; Time of unloading; Rate of empty running at each level of the SC; Amount of slack in deliveries or pick-up's schedule, for managing backloads; and Geographical variabilities.

In this paper, we are concerned by SC network Design problem, rather than Fleet Sizing & Vehicle Routing problems. From the strategic perspective, we think that the first type of design problem must be talked in first, and tactically, should be followed by the second type to capture all the operational factors. We refer the reader to (Hoff *et al.* 2010), for details on fleet composition and routing.

The figure **2** illustrates an example of freight transport configuration corresponding to a customer Dj belonging to a given distribution segment, which is fed by two clusters of warehouses $\{O_1,\ldots,O_m,\ldots,O_k\}$ & $\{O_{k+1},\ldots,O_n\}$.

We suggest a constructive (not a normative) freight transport costs model, which is based on some relevant factors extracted from the recent logistics literature (Torrey & Murray, 2015; van den Engel, 2010; Browne *et al.* 2009). The factors considered for different truck configurations are reported in the table **2.1.**

To determine the annual fixed cost $fCostT$ and the variable cost vc_T , we consider the figure **2.2**:

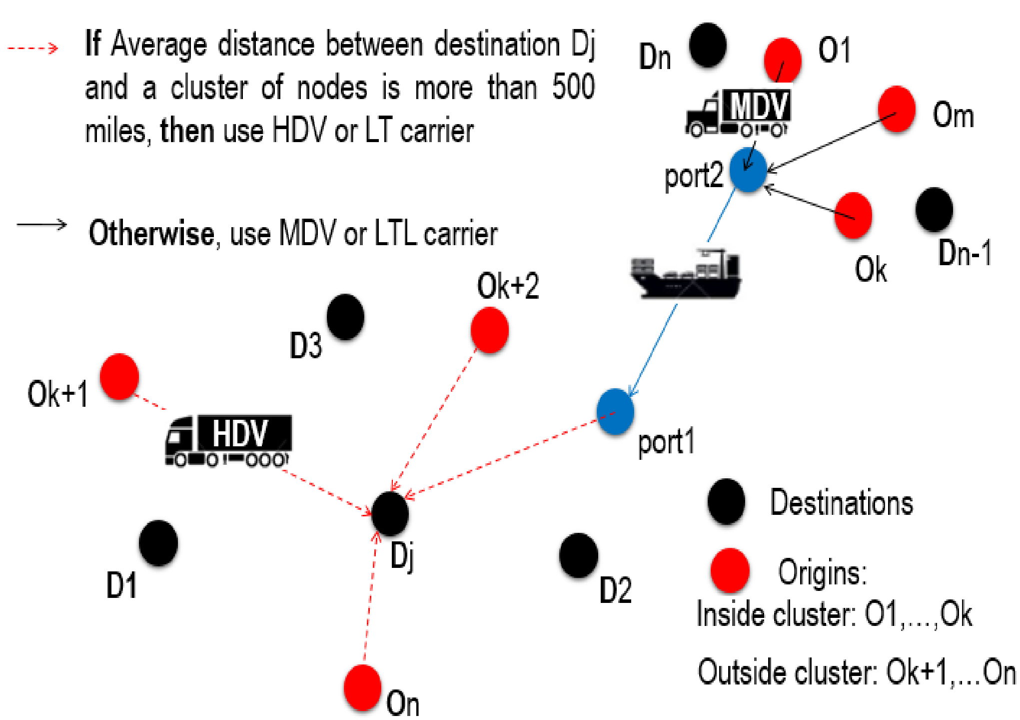


Fig. 2.2. Freight transport configuration to feed a destination Dj by two clusters of origins $\{O_1,\ldots,O_m,\ldots,O_k\}$ & $\{O_{k+1},\ldots,O_n\}$

Table 2.1

Fixed cost & variable cost of truck configurations:

Region	ε Empty run rate	Type of truck	Average Speed (km/ hour)	Annual fixed cost ($)	Variable cost ($/TEU. Km)
North America	0.16 to 0.18	HDV	64.0	42 762	0.32
		MDV		45 483	0.14
Europe	0.28 to 0.24	HDV	50.6	14 000	0.59
		MDV		14 900	0.68

(*) TEU: Twenty-foot Equivalent Unit container (20x8x8 feet)

Suppose that the destination Dj expects for an annual demand d^{p}_{Dj}. A fraction β of the demand is projected to be sourced from the outside cluster $\{O_1,...,O_m,...,O_k\}$, and the remainder $(1-\beta)$ from the inside cluster $\{O_{k+1},...,O_n\}$.

$Trip_{Om,Dj}$: The trip between the origin (Om) and the destination (Dj).

$$Trip_{Om,Dj} = Trip_{Om,port2} + Trip_{port2,port1} + Trip_{Port1,Dj}$$

$$CostT_{Om,Dj} = fCostT_{Om,Dj} + vCostT_{Om,Dj}$$

** $fCostT_{Om,Dj}$ is the total fixed cost of the fleet assigned to move annually all the products *p* from the origin Om to the destination Dj.

** $vCostT_{Om,Dj}$ is the total variable cost incurred to transport the volume $\sum_p q^p_{Om,Dj}$ of products p from Om to Dj.

$$fCostT_{Om,Dj} = fCostT_{Om,port2} + fCostT^{Om}_{port1,Dj}$$

$$fCostT_{Om,Dj} = \sum_p \left\{ \begin{array}{l} fc_{truck2}.N^{Om,port2}_{p,truck2} \\ +fc_{truck1}.N^{Om/port1,Dj}_{p,truck1} \end{array} \right\}$$

$N_{p,truck2}^{Om,port2}$: Number of trucks with capacity cap_{truck2}^{p} required to move the expected demand $\frac{\beta}{k}.d_{Dj}^{p}$ of a product p, from the origin Om to the destination Dj, during the effective annual time T_{eff}.

$N_{p,truck1}^{Om/port1\text{-}2,Dj}$: Number of trucks with capacity cap_{truck1}^{p} required to move the expected demand $\frac{\left[\frac{\beta}{k}\right]+(1-\beta)}{n}.d_{Dj}^{p}$ of a product p from the origin Om belonging to the cluster outside, via the ports 1&2 to the destination Dj, during the effective annual time T_{eff}

T_{eff} = (2/3) Shift. (24) Hours/day. (5/7) days. (365) days/year

= 4 171.4 Hours/year

fc_{truck2} & fc_{truck1} : Respectively are the fixed cost to operate annually the full capacity of truck2, and truck1 (See the table **2.1**)

$$\mathbf{fCostT_{Om,Dj}} = \sum_{p}\frac{1}{T_{eff}}\left\{\left[\frac{\beta}{k}\right].fc_{truck2}\frac{T_{Trip2}}{cap_{truck2}^{p}} + \left[\frac{\frac{\beta}{k}+(1-\beta)}{n}\right].fc_{truck1}\frac{T_{trip1}}{cap_{truck1}^{p}}\right\}.d_{Dj}^{p} \qquad (i,1)$$

$T_{Trip} = Time_{Trip} = t\,(Load) + t\,(Transport) + t\,(Unload)$

The time of waiting is not considered in this paper.

$t_{Transport_{Om,port2}} = (1+\varepsilon 2)\frac{\bar{\delta}_2}{v2}$; is the average time to perform the land trip from Om to the port2, with a standard speed v2, by considering a rate of empty running $\varepsilon 2$, which depends on the geographic area, and the nature of distribution (sourcing, inbound, outbound, or reverse logistics).

See table 1

$t_{Transport_{Om/port1,port2}} = (1+\varepsilon 1)\frac{\bar{\delta}_1}{v1}$; is the average time to perform the land trip from the port1 to the destination Dj, with a standard speed v1, by considering a rate of empty running $\varepsilon 1$

$$\bar{\delta}_2 = \sum_{i=1}^{k} \frac{\delta_{port2,Oi}}{k} \quad \& \quad \bar{\delta}_1 = \frac{\delta_{port2,D} + \sum_{i=k+1}^{n} \delta_{Oi,D}}{n-k+1}$$

$\bar{\delta}_2$: Average distance between port 2, and origins O_i (i=1 to k)

$\bar{\delta}_1$: Average distance between the destination Dj, and origins O_i (i = (k+1) to n), plus port 1

Concerning the variable cost of transportation;

$$vCostT_{Om,D} = \sum_p vc^p_{TOm,D} . q^p_{Om} \text{ , where}$$

$$vc^p_{T_{Om,D}} = vc^p_{T_{Om,port2}} + vc^p_{T_{port2,port1}} + vc^p_{T_{port1,D}}$$

$$vc^p_{T_{Om,port2}} = vc^p_{Truck2} . \delta_{Om,port2} . weight_p$$

$$vc^p_{T_{port1,D}} = vc^p_{Truck1} . \delta_{port1,D} . weight_p$$

$$vc^p_{T_{port2,port1}} = \frac{vc_{sea}}{Y^p_{C20}}$$

vc^p_{truck2} & vc^p_{truck1} : Respectively, unit variable cost of transporting privately a ton of product p for one kilometer, in the truck2 with capacity cap^p_{truck2} (cap^p_{truck1}),

q^p_{Om} : Annual units of product p, moved from the origin Om to the destination Dj, via the ports2-1,

Y^p_{C20} : Total units of product p, which may be loaded in the container (20x8x8 feet) for shipping

vc_{sea} : Variable cost for privately managing the maritime transport of a TEU (*) of product, from one port to another.

$weight_p$: Weight in ton of a unit of product p

For instance:

$vc_{Qindao,Vancouver}$ = (\$)1400 / TEU(*), in 56 hours

$vc_{Rotterdam,NewYork}$ = (\$) 2000 / TEU(*), in 64 hours

(*) *TEU*: Twenty-foot Equivalent Unit container (20x8x8 feet)

The Unit variable cost of transportation is:

$$vc^{p}_{TOm,D} = \left\{ \begin{array}{l} vc^{p}_{truck2}.\delta_{Om,port2} + \frac{vc_{sea}}{Y^{p}_{C20}.weight_{p}} \\ +vc^{p}_{truck1}.\delta_{port1,D} \end{array} \right\} \quad (i,2)$$

❖ X: Warehousing

The FC has to decide between leasing and managing a set of warehouses with flexible capacities, and outsourcing the warehousing operation. In this paper, we consider the conventional rectangular warehouses, which are often used in practice (Grosse & Glock, 2015). They consist of several parallel aisles; front and back access aisles, and a depot in the front aisle. Products are assigned to storage locations based on the demand frequencies of the products. So, the standard products p1 with the highest demand frequencies are stored in the aisles closest to the depot, followed by hybrid products p3 in aisles with a medium distance from the depot. Innovative products p2 with low demand frequencies are stored in the aisles farthest from the depot.

To estimate the warehousing costs, the following assumptions are considered:

- Discrete non-perishable products *p*;
- 100% pallet in and 100% out, and only standard pallet is used (40''x 48'' = 3 1/3 ft. × 4ft);
- Pallets stored three high;
- All inbound and outbound are via truck load;
- Productivity labor ε_{Labor} assumed equal to 25 pallets/ hour inbound, 25 pallets/ hour outbound;
- Only 70% of the warehouse space can be used to store products; and
- Electrical forklifts are only used to handle materials in the warehouse.

** The fixed cost $fCostW_{w}$ of a warehouse w=

Cost of leasing warehouse NNN (triple Net: N-property tax; N-insurance; & N-Maintenance) + Cost of leasing "electrical" forklifts;

The cost of leasing warehouse NNN = ($ 5, 5 / square foot per year) * Ω_W ;

Where

Ω_W : : The squared feet facility *w*, which is proportional to the maximum of product units to store in the warehouse w (subscribed capacity of warehousing $\sum_p Cap_{pw}$). It depends on the staking mode (e.g. Pallet three high), the number of items per pallet N_p , and the dimensions of the used pallet (e.g. Standard pallet: 40''x 48'').

$$\Omega_W(ft^2) = 1{,}3.\left(13{,}33(ft^2).\sum_p \frac{Cap_{pw}}{3N_p}\right)$$

So, Cost of leasing warehouse NNN ($) = $31{,}79(\$).\sum_p \frac{Cap_{pw}}{N_p}$

Cost of leasing "electrical" forklifts = ($ 750/ forklift/ month) * (12 months) * N_{FL}

N_{FL} : Number of electrical forklifts required for processing goods. It depends and the capacity of warehousing, the Inventory Turnover Rate of each product ITR_p , the mode of staking, the productivity of labor, and the effective time of warehousing.

$$N_{FL} = \frac{\frac{2}{\varepsilon_{Labor}}.\sum_p \left(\frac{Cap_{pw}.ITR_p}{N_p}\right)}{7(hours/days).2shifts.5(days/week).52weeks}$$

So, fixed cost of warehousing is:

$$\mathbf{fCostW_W} = \sum_p \left(\frac{\mathbf{31{,}79(\$) + 0{,}1978(\$).ITR_p}}{\mathbf{N_p}}\right)\mathbf{Cap_{pw}} \qquad (i,3)$$

** The variable cost $vCostW_W$ of the warehouse w is:

$vCostW_W = \sum_p vc_{W_p}.q_{pw}$, where

q_{pw} : Annual units of product *p* processed in the warehouse w;

vc_{W_p} : Variable cost for privately processing a unit of product p in any warehouse w

$vc_{W_p} = \frac{u_{Labor}}{\varepsilon_{Labor_p}}$, where

u_{Labor} : Fully loaded hourly cost per warehouse worker: (includes, clerical, supervision, energy, etc.)

$u_{Labor} = 2,5.\text{Direct labor hourly rate}$

$u_{Labor} \approx 2,5.(\$)15,20\ /\ \text{hour} = \$38\ /\ \text{hour}$

ε_{Labor} : Productivity Labor

$$vc_{w_p} = \frac{2.38(\$/hour)}{25(pallet/hour).N_p} = \frac{3,04}{N_p}(\$\ /\ unit) \quad \text{(i,4)}$$

- ❖ X: Reprocessing returns of products

In Baker & Canessa (2009), a distribution center design should be centred on the value-added operations, storage and handling equipment, and that the building should then be designed around these. Reprocessing the returns of products for remanufacturing consists of a series of operations. This, involves an additional fixed cost in terms of space, materials handling, and equipment (e.g. Gravity roller conveyor; Trans-pallet; oscilloscope, electrical screwdrivers, penetrating oil to loosen screws, etc.), and involves a variable cost in terms of work force performing operations, within an expected processing time t_{Cycle} per item.

According to Baker & Canessa (2009), the additional space required in a potential hybrid warehouse *w* may be divided into two areas: One for sorting product returns (e.g. assembled products), and the other for storing both the input, recoverable and unrecoverable products;

The space of reprocessing may be designed as a flexible number of workstations, with a “U” shaped layout (Grosse & Glock, 2015**)**, and a square foot Ω_w^R per single workstation, operating two shifts per day. The figure **2.3** illustrates the workstation as follows:

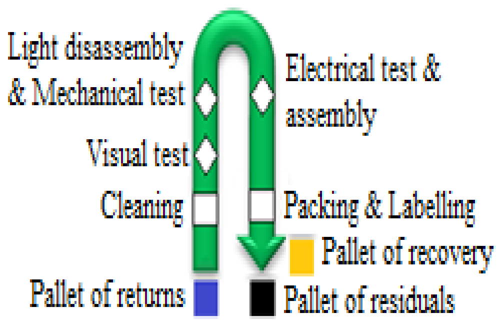


Fig.2.3. 'U' shaped layout work station for reprocessing a returned product

The annual number of items which may be reprocessed in a single workstation is:

$$\frac{2(\text{shifts}).7(\text{hours}).5(\text{days/week}).52\text{weeks}}{t_{Cycle}(\text{hour})} = \frac{3640}{t_{Cycle}(\text{hour})};$$

So the required number of workstations is $\frac{t_{Cycle}\cdot\sum_{p} CapR_{pw}}{3640}$, and the required surface is $\Omega_w^R \cdot \frac{t_{Cycle}\cdot\sum_{p} CapR_{pw}}{3640}(\text{feet})$, where $\sum_{p} CapR_{pw}$ is the subscribed annual capacity of the returns products *p* to be reprocessed in the hybrid warehouse w.

The space required for storing returned products may be determined like the case of warehousing, by the formula:

$$\Omega'_w(ft^2) \approx 5,78.\sum_{p} \frac{CapR_{pw}}{N_p.ITR};$$

ITR : Average of Inventory Turnover Product of the returned products.

The number of electrical forklifts required for reprocessing product returns is

$$N'_{FL} = \frac{\frac{2}{\varepsilon_{Labor}}.\sum_{p} \frac{CapR_{pw}}{N_p}}{7(\text{hours / days}).2\text{shifts}.5(\text{days / week}).52\text{weeks}}$$

** The fixed cost of reprocessing is:

$$\mathbf{fCostHW_w} = \sum_{p}\left\{\left(5,5\,.\Omega_w^R\,.\frac{t_{Cycle}}{3640}+\frac{31.79}{N_p.ITR}\right)+\frac{1.09}{N_p}\right\}CapR_{pw} \qquad (i,5)$$

** The Variable cost of reprocessing is:

$$vCostHW_w = \sum_p vc_{HW}.q_{pw}^R$$

q_{pw}^R : Annual units of returned product *p* reprocessed in the hybrid warehouse *w*;

vc_{HW} : Unit Variable cost for privately reprocessing the product p in any hybrid warehouse w

$$vc_{HW} = \frac{u_{Labor}}{\varepsilon_{Labor}^r} = \frac{38(\$/hour)}{\varepsilon_{Labor}^r}$$, where

ε_{Labor}^r : A productivity labor in reprocessing, which depends on the t_{Cycle}

$$\mathbf{vc_{HW}} = \frac{2,5.15,2(\$/hour)}{1/t_{Cycle}(hour)} = 38.t_{Cycle}.(\$/unit) \qquad (i,6)$$

2.3.2.2. *Logistics GHG emissions computing models:*

The GHG Protocol Corporate Standard provides a guidance for companies to prepare their GHG emissions inventories, and seven GHG are covered by the Kyoto Protocol (WRI/WBCSD, 2004):

Carbon dioxide (CO_2); Methane (CH_4); Nitrous oxide (N_2O); Hydro-fluorocarbons (HFCs);

Per-fluorocarbons (PFCs); Sulphur hexafluoride (SF_6); and Nitrogen tri-fluoride (NF_3).

In this paper, we consider only the most measurable GHG: CO_2 with the reactive factor (Global Warming Potential) GWP=1; CH_4 with GWP=25; N_2O with GWP=298; and HCF, especially CH_2FCF_3 (R 134a), with GWP= 1430.

There are basically two approaches, to determine GHG emissions of logistics operations: The energy-based approach, and the activity-based approach (McKinnon & Piecyk, 2011).

In the first approach, energy used in logistics activities is recorded, and standard emission factors are employed to convert energy value into carbon equivalent emissions. In the case of energy data absence, it is possible to make a rough estimate of the default factors of GHG emissions, by applying the second approach. In the second vein, we determine the default factors of GHG emissions presented in the table **2.2**, by considering the following assumptions:

- The refrigerant R134a is used in the refrigeration system of tractors (not the trailers), with a quantity of 3, 43 kg for MDV (28-foot), and 4, 28 kg for HDV (53-foot)), and the annual evaporative leakage rate is about 25% (Tunnell, & Fender, 2010);
- The Energy consumption of Air conditioning of a warehouse is estimated to an average of 22 Btu / ft^2, which represents about 8% of the total electricity consumption; according to U. S. Energy Information Administration & CBECS (2003);
- The *e*missions & *G*eneration *R*esource *I*ntegrated *D*atabase (*eGRID*), and *non-eGRID* average emission factors for U.S. Electricity Use are: 1367 lbs CO2 / GWh; 20 lbs N_2O / GWh; and 47 lbs CH_4 / GWh (Tunnell, & Fender, 2010).
- The amount of GHG emission resulting from disposal of one kilogram may be extracted from references such as http://www.rcbc.ca/files/u3/ICF-final-report.pdf (refer to page 95, microwave oven is taken as example in the table **2.2**); and
- The warehouses, and collection centres use standard pallets (3 1/3 ft. × 4ft.), which are stored in three high.

By analogy with the cost formulas, the GHG emissions amount of a logistics operation *X* may be expressed as:

$$\mathbf{FCCO2(X)} = \left\{ \mathbf{fe(X)} + \mathbf{ve_X . q(X)} \right\} \quad \text{(iii)}$$

fe(X) : Fixed amount of GHG emissions coming from the private physical asset of *X*, during one year

ve_X : Variable amount of GHG emission coming from the combustion of fuel, or the production of electricity, which are used in activity *X*, to privately operate a unit of product p.

❖ X: Transportation:

$$FCCO2T_{Om,Dj} = feT_{Om,Dj} + \sum_{p} vc^{p}_{TOm,Dj} .q^{p}_{Om}$$

$$feT_{Om,Dj} =$$

$$\sum_{p} \frac{1}{Teff} \left\{ \begin{array}{l} \left[\frac{\beta}{k}\right].fc_{truck2} \frac{T_{Trip2}}{cap^{p}_{truck2}} \\ + \left[\frac{\frac{\beta}{k}+(1-\beta)}{n}\right].fc_{truck1} \frac{T_{trip1}}{cap^{p}_{truck1}} \end{array} \right\} .d^{p}_{Dj} \qquad \text{(iii,1)}$$

$$ve^{p}_{TOm,Dj} = weight_{p}. \left\{ \begin{array}{l} vCO2_{truck2}.\delta_{Om,port2} \\ + \frac{vCO2_{maritime}}{Y^{p}_{C20}.weight_{p}} \\ +vCO2_{truck1}.\delta_{port1,Dj} \end{array} \right\} \qquad \text{(iii,2)}$$

$fCO2_{truck1}$ & $fCO2_{truck2}$	Respectively, are the annual evaporative fluorocarbon emission (Ton EqCO2), coming from the refrigeration of the truck 1 (truck2)
$vCO2_{truck1}$ & $vCO2_{truck2}$	Respectively, are the unit variable emissions of CO2, CH4, and N2O emissions coming from the combustion fuel in truck 1 (truck2) to move one ton of any product, for one kilometer.
$vCO2_{sea}$	Unit variable emissions of CO2, CH4, and N2O emissions coming from the combustion fuel in vessel to move 1 TEU, between two ports.

❖ X: Warehousing

$$FCCO2W_{w} = fe_{W} + \sum_{p} ve_{Wp} q_{pw}$$

$$fe_{W} = \sum_{p} \frac{3.1{,}688.10^{-6}.0{,}08(tonCO2eq)}{13{,}33} . \frac{5{,}78}{N_{p}} .Cap_{pw} \qquad \text{(iii, 3)}$$

$$ve_{Wp} = \frac{3.1{,}688.10^{-6}.0{,}92(tonCO2)}{13{,}33(ft^{2})} . \frac{5{,}78}{N_{p}} (ft^{2}) \qquad \text{(iii, 4)}$$

❖ X: Reprocessing returns of products:

$$FCCO2HW_w = fe_{HW} + \sum_p ve_{HW_p} q_{pw}$$

$$fe_{HW} = \sum_p \left\{ \begin{array}{l} 0{,}030384.10^{-6}(tonCO2eq) \\ .\left(\Omega^R_w . \frac{t_{Cycle}}{3640} + \frac{5{,}78}{N_p.ITR} \right) \end{array} \right\} .CapR_{pw} \qquad \text{(iii, 5)}$$

$$ve_{HWp} = \frac{3.1{,}688.10^{-6}.0{,}92(tonCO2)}{13.33(ft^2)} . \frac{5{,}78}{N_p}(ft^2) \qquad \text{(iii, 6)}$$

In the case of outsourcing logistics activities to 3PL, and according to the research of MIT Center for Transportation & Logistics (Blanco & Craig, 2009), a significant GHG emission inefficiency of 20 to 30% can be observed by outsourcing operations:

Concerning the freight transportation, and comparing the network configuration of the focal company FC and the 3PL, the 3PL tend to use a flexible routing network strategy, rather than a point-to-point strategy, to consolidate the freight of different customers (Hesse & Rodrigue, 2004). This can generate a lot of stops between different origins and destinations, hardly avoid traffic congestion, increase the distances, and therefore raise the GHG emissions, notably CO2, N2O, and CH4.

Concerning the warehousing and reprocessing operations, we suppose that:

The fixed GHG emissions are not affected by the asset ownership statute, and the FC are more efficient that 3PL to rationalize the energy utilization within warehouses by controlling the frequency of entrances and exits.

$$(3PL)CO2X = \left\{ \begin{array}{l} fCO2X + \\ \zeta^{3PL}_X .vCO2X \end{array} \right\} .quantity(X) \qquad \text{(iv)}$$

ζ^{3PL}_X : Adjustment factor of GHG emissions, relative to the logistics activity X

$1.20 \leq \zeta^{3PL}_X \leq 1.30$

Table 2.2

Default GHG emissions factors collected from specialized documents:

ATRI: American Transportation Research Institute, 2010; U.S. Environmental Protection Agency, 2008; Clean Cargo /BSR, 2012.

<table>
<tr><th>Default factors of GHG emissions</th><th colspan="4">Scope 1
(In-house)
Direct emissions</th><th colspan="2">Scope 2
(In-house)
Indirect emissions</th><th colspan="5">Scope 3
(Outsourcing)
Optional Indirect emissions</th></tr>
<tr><td rowspan="6">Transportation</td><td rowspan="4">Mobile fuel combustion</td><td rowspan="4">CO_2 + N_2O + CH_4</td><td rowspan="2">MDV</td><td>In North America:
759. 70 g CO_{2Eq} / TEU. Km</td><td rowspan="6" colspan="2"></td><td rowspan="4">Mobile fuel combustible</td><td rowspan="4">CO_2 + N_2O + CH_4</td><td>LTL</td><td colspan="2">964.80 g CO_{2Eq} / TEU. Km</td></tr>
<tr><td>In EU:
888. 85 g CO_{2Eq} / TEU. Km</td><td>TL</td><td colspan="2">509.70 g CO_{2Eq} / TEU. Km</td></tr>
<tr><td rowspan="2">HDV</td><td rowspan="2">In North America:
401. 30 g CO_{2Eq} / TEU. Km</td><td rowspan="2">Sea transport</td><td>EU-North America EC</td><td>75.9 g CO_{2Eq} / TEU. Km</td></tr>
<tr><td>Asia-North America WC</td><td>65.1 g CO_{2Eq} / TEU. Km</td></tr>
<tr><td rowspan="2">Refrigerant usage (not reefer container)</td><td rowspan="2">HFCs: R134a</td><td>MDV</td><td>1226
kg CO_{2Eq} /vehicle</td><td rowspan="2">Refrigerant usage (not reefer container)</td><td rowspan="2">HFCs: R134a</td><td>LTL</td><td colspan="2">1226
kg CO_{2Eq} /vehicle</td></tr>
<tr><td>HDV</td><td>1530 kg CO_{2Eq} /vehicle</td><td>TL</td><td colspan="2">1530
kg CO_{2Eq} /vehicle</td></tr>
<tr><td>Warehousing & Reprocessing</td><td colspan="4"></td><td>Electricity usage</td><td>1.688 g CO_{2Eq} / stored pallet</td><td>Electricity usage +</td><td colspan="4">2.110 g CO_{2Eq} / stored pallet</td></tr>
<tr><td>Disposal</td><td colspan="6"></td><td>CO_2 + N_2O + CH_4</td><td colspan="4">2. 481 g CO_{2Eq} /Kg of discarded product</td></tr>
</table>

Conversion: 1 km = 0. 6214 miles; 1lb = 0. 45359 kg; 1gallon = 3. 785412 liters; 1kWh= 3412. 1416 Btu

Table 2.3

Expected annual quantity of product return R_{tbpk} from customer k, for each product p with a fraction of return r_{bp}, at period t (= 1 to 6), for scenario b

Year t	Demand	(R_{tbpk}) Expected return of product *p*
1	D_{1bpk}	$r_{bp}D_{1bpk}$
2	D_{2bpk}	$r_{bp}D_{2bpk} + r_{bp}(1-r_{bp})^1 D_{1bpk}$
3	D_{3bpk}	$r_{bp}D_{3bpk} + r_{bp}(1-r_{bp})^1 D_{2bpk} + r_{bp}(1-r_{bp})^2 D_{1bpk}$
4	D_{4bpk}	$r_{bp}D_{4bpk} + r_{bp}(1-r_{bp})^1 D_{3bpk} + r_{bp}(1-r_{bp})^2 D_{2bpk} + r_{bp}(1-r_{bp})^3 D_{1bpk}$
5	D_{5bpk}	$r_{bp}D_{5bpk} + r_{bp}(1-r_{bp})^1 D_{4bpk} + r_{bp}(1-r_{bp})^2 D_{3bpk} + r_{bp}(1-r_{bp})^3 D_{2bpk} + r_{bp}(1-r_{bp})^4 D_{1bpk}$
6	D_{6bpk}	$r_{bp}D_{6bpk} + r_{bp}(1-r_{bp})^1 D_{5bpk} + r_{bp}(1-r_{bp})^2 D_{4bpk} + r_{bp}(1-r_{bp})^3 D_{3bpk} + r_{bp}(1-r_{bp})^4 D_{2bpk} + r_{bp}(1-r_{bp})^5 D_{1bpk}$

2.4. Modelling & Solving approaches

2.4.1. Problem formulation

During a set of periods T (indexed $t \in T$), the focal company FC, which controls the whole closed loop SC described in the section 3, desires optimizing its SC, by minimizing two objective functions:

- Total expected logistics cost ***OBJ1*** (1), and
- Total expected logistics GHG emissions ***OBJ2*** (2).

** *Objective functions:*

OBJ1*: minimize Z*

Z: Expected total logistics cost ($ US)

$$\boldsymbol{Z = Z_1 + Z_2 + Z_3 + Z_4 + Z_5 + Z_6 + Z_7 + Z_8 + Z_9} \quad (1)$$

Z_1: Freight transport cost from suppliers to plants

Z_2: Freight transport cost from plants to warehouses

Z_3: Freight transport cost from warehouses to customers' zones

Z_4: Freight transport cost from distribution segments to reprocessing centers (hybrid warehouses & collection centers)

Z_5: Freight transport cost of recoverable product from reprocessing centers to plants

Z_6: Freight transport cost of unrecoverable product from reprocessing centers to disposal centers

Z_7: Cost of Warehousing

Z_8: Cost of Reprocessing

Z_9: Cost of Disposal

See analytical expressions of $Z_{i=1,6}$ in table **2.5**, and

$Z_{i=7,9}$ in table **2.6**.

OBJ2*: minimize C*

$$\boldsymbol{C = C_1 + C_2 + C_3} \quad (2)$$

C_1: Direct CO_2, N_2O, CH_4, HFC (R-143a) emissions from leased or purchased fleet operating within the Closed loop-SC:

The Scope 1, according to The Greenhouse Gas Protocol (WRI & WBCSD, 2004).

C_2: Indirect GHG emissions associated to the purchase and use of electricity within potential FC's warehouses & hybrid warehouses; The Scope 2, according to The Greenhouse Gas Protocol (WRI & WBCSD, 2004).

C_3: Indirect emissions associated to any outsourced logistics services; The Scope 3, according to The Greenhouse Gas Protocol (WRI & WBCSD, 2004)

See analytical expressions of C_1 and C_2 in table **2.7**, and C_3 in table **2.8**.

** Decision variables: Strategic, and tactical variables

The logistics activities are freight transportation, warehousing, reprocessing of product returns, and disposal of unrecoverable products. These logistics activities are subject of total or partial outsourcing.

- *Boolean decision variables (Strategic)*

x_{sm} : =1 if FC in-sources transportation of the category of supplies s, from corresponding suppliers to plant m. Otherwise = 0;

x_W : =1 if FC in-sources transportation of products, from any plant to the warehouse w. Otherwise = 0;

x_V : =1 if FC in-sources transportation of products, from any plant to the 3PL warehouse v. Otherwise = 0;

x_{Wk} : =1 if FC in-sources transportation of products, from any FC's warehouse to the customer zone k. Otherwise = 0;

x_{Vk} : =1 if FC in-sources transportation of products, from any 3PL's warehouse to the customer zone k. Otherwise = 0;

x_{iw} : =1 if FC in-sources transportation of returned products, from the distribution segment i to the FC's warehouse w. Otherwise = 0;

x_{iu} : =1 if FC in-sources transportation of returned products, from the distribution segment i to 3PL's collection center u. Otherwise = 0;

x_{HWm} : =1 if FC in-sources transportation of recoverable products, from hybrid warehouses to the plant m. Otherwise = 0;

x_{Um} : =1 if FC in-sources transportation of recoverable products, from collection centers to the plant m. Otherwise = 0;

x_{HWz} : =1 if FC in-sources transportation of unrecoverable products, from hybrid warehouses to the 3PL's disposal center z. Otherwise = 0;

x_{Uz} : =1 if FC in-sources transportation of unrecoverable products, from collection centers to the 3PL's disposal center z. Otherwise = 0;

y_w : =1 if FC's warehouse w is open. Otherwise = 0;

Y_w : =1 if w is open as a hybrid warehouse. Otherwise = 0;

- *Integer decision variables (Tactical)*

$$\left\{\begin{matrix} q_{tbpsnm}; \\ q_{tbpmw} \,\&\, q_{tbpmv}; \\ q_{tbpwk} \,\&\, q_{tbpvk}; \\ q_{tbpkw} \,\&\, q_{tbpku}; \\ q_{tbpwm} \,\&\, q_{tbpum}; \\ q_{tbpwz} \,\&\, q_{tbpuz} \end{matrix}\right\}$$

Number of units of supplies, products, returns, recoverable products, and unrecoverable products transported from the node *i* to node *j* of the SC, at a period $t \in T$, and within scenario $b \in B$. Where; $s \in S$; $n \in N$; $p \in P$; $m \in M$; $w \in W$; $v \in V$; $k \in K$; $u \in U$; & $z \in Z$.

The model has two types of parameters: Deterministic, and stochastic parameters.

** *Deterministic Parameters:*

h : Rate of inflation

λ_s : Maximum fraction of supply s, which can be purchased from a supplier (e. g. Security of supply)

κ_{pm} : Quota of manufacturing and remanufacturing the product p in the plant m (e. g. Manufacturing strategy)

$weight_p$: Weight of a unit of product p

$weightR_p$: Weight of a unit of returned product p

$weight_s$: Average weight of supply s required to manufacture a unit product,

ITR_p : Inventory turnover rate of p in any warehouse (e.g. Standard, Innovative, and Hybrid products)

$ve_{T_{snm}}$: Variable GHG emissions in (Tons of CO2eq/Ton. Km) of transporting privately the supplies required by plant m, from the corresponding supplier n,

$ve_{T_{pmw}}$: Variable GHG emissions in (Tons of CO2eq/Ton. Km) of transporting privately the product p, from the plant m, to the warehouse w

$ve_{T_{pmv}}$: Variable GHG emissions in (Tons of CO2eq/Ton. Km) of transporting privately the product p, from the plant m, to the warehouse v

$ve_{T_{pwk}}$: Variable GHG emissions in (Tons of CO2eq/Ton. Km) of transporting privately the product p, from the warehouse w, to the customer zone k

$ve_{T_{pvk}}$: Variable GHG emissions in (Tons of CO2eq/Ton. Km) of transporting privately the product p, from the warehouse v, to the customer zone k

$ve_{TR_{pkw}}$: Variable GHG emissions in (Tons of CO2eq/Ton. Km) of transporting privately the returned product p, from the customer zone k to the hybrid warehouse w

$ve_{TR_{pku}}$: Variable GHG emissions in (Tons of CO2eq/Ton. Km) of transporting privately the returned product p, from the customer zone k to the collection center u

$ve_{THW_{pwm}}$: Variable GHG emissions in (Tons of CO2eq/Ton. Km) of transporting privately the recoverable product p, from the hybrid warehouse w, to the plant m

$ve_{TU_{pum}}$: Variable GHG emissions in (Tons of CO2eq/Ton. Km) of transporting privately the recoverable product p, from the collection center u, to the plant m

$ve_{THW_{pwz}}$: Variable GHG emissions in (Tons of CO2eq/Ton. Km) of transporting privately the unrecoverable product p, from the hybrid warehouse w, to the disposal center z

$ve_{TU_{puz}}$: Variable GHG emissions in (Tons of CO2eq/Ton. Km) of transporting privately the unrecoverable product p, from the collection center u, to the disposal center z

$ve_{W_{pw}}$: Variable GHG emissions in (Tons of CO2eq/Ton of product) of warehousing privately the product p, in the warehouse w

$ve_{HW_{pw}}$: Variable GHG emissions in (Tons of CO2eq/Ton of returned product) of reprocessing privately the used product p, in the hybrid warehouse w

** *Stochastic parameters*:

To capture the uncertainty relative to: 1) demand of multi-product p; 2) extended capacities of facilities to face demand; 2) quantity of product returns; 3) quality of product returns; and 4) different logistics variable costs, a stochastic plan for a limited horizon of time T may be established by using a scenarios based approach.

To do so, we suppose that the FC resorts to a strategic consulting to indorse or adapt the assumptions of constructive models; and the deterministic parameters, and to model the behavior of uncertain parameters.

Drawing our inspiration from Serrato *et al.* (2007), we suppose that within a scenario b, the demand of product p at the period t = 1 is D_{1bp}, and the amount of returns is $r_{bp}D_{1bp}$, where r_{bp} is the average fraction of product returns p corresponding to the current demand. The demand at *t* = 2 is D_{2bp}, but the amount of returns will be $r_{bp}D_{2bp} + r_{bp}(1 - r_{bp})D_{1bp}$. The demand at *t* = 3 is D_{3bp}, but the amount of returns will be $r_{bp}D_{3bp} + r_{bp}(1 - r_{bp})^1 D_{2bp} + r_{bp}(1 - r_{bp})^2 D_{1bp}$, and so on (See the table **2.3**).

Following Pishvaee et *al.* (2008), within a no long interval of time, say 6-10 years, all possible scenarios describing the behaviour of uncertain parameters may be elaborated by means of semantic attribution (e. g. High, Medium; Low). According to the strategic consulting group, expected annual values of the parameters are adopted. These possible scenarios may be aggregated into a set of most probable scenarios B (indexed $b \in B$), say 5-7 probable scenarios within the time interval. The dynamic change between scenarios needs to be approached by a transition matrix, which “ideally” should be constant in time (Meyn & Tweedie, 1996). In other words, the system of parameters is considered as a Markov chain, in which the future behaviour of the system is determined only by its present state, and it is independent of the way in which this state has developed. If not so, the stochastic plan may include more than one transition matrix switching between themselves (Horn, 1975)

We basically consider the dynamic change of scenarios following a Markov Chain with one constant matrix of transition. So, the marginal probabilities of scenarios at a given period t may be determined by the formula Chapman-Kolmogorov (Ross, 2009). The table **2.4** gives an example of a stochastic plan relative to the working case study of a FC which manufactures, distributes, and reprocesses three technologies of microwave ovens.

Hereunder, we list the stochastic parameters:

$prob_{tb}$: Marginal probability occurrence of the scenario b, at t.

$fc_{T_{tbsm}}$ & $fe_{T_{tbsm}}$: Respectively, the annual fixed cost in ($) (GHG emissions in Tons of CO2eq) of transporting privately the supplies s required by plant m, at period t for scenario b.

$vc_{T_{tbsnm}}$: Variable cost in ($/Ton of supply s) of transporting privately the supplies required by plant m, from the corresponding supplier n, at period t for scenario b.

$c_{T^{3PL}_{tbsnm}}$ & $e_{T^{3PL}_{tbsnm}}$: Respectively, the outsourcing cost in ($/Ton of supply s) (GHG emissions in Tons of CO2eq/Ton. Km) of transporting the supplies required by plant m, from the corresponding supplier n, at period t for scenario b.

$fc_{T_{tbw}}$ & $fe_{T_{tbw}}$: Respectively, the annual fixed cost in ($) (GHG emissions in Tons of CO2eq) of transporting privately products, from plants to the FC's warehouse w, at period t for scenario b.

$vc_{T_{tbpmw}}$: Variable cost in ($/Ton of product p) of transporting privately the product p, from the plant m, to the warehouse w, at period t for scenario b.

$c_{T^{3PL}_{tbpmw}}$ & $e_{T^{3PL}_{tbpmw}}$: Respectively, the outsourcing cost in ($/Ton of product p) (GHG emissions in Tons of CO2eq/Ton. Km) of transporting the product p, from the plant m, to the warehouse w, at period t for scenario b.

$fc_{T_{tbv}}$ & $fe_{T_{tbv}}$: Respectively, the annual fixed cost in ($) (GHG emissions in Tons of CO2eq) of transporting privately products, from plants to the 3PL's warehouse v, at period t for scenario b.

$vc_{T_{tbpmv}}$: Variable cost in ($/Ton of product p) of transporting privately the product p, from the plant m, to the warehouse v, at period t for scenario b.

$c_{T^{3PL}_{tbpmv}}$ & $e_{T^{3PL}_{tbpmv}}$: Respectively, the outsourcing cost in ($/Ton of product p) (GHG emissions in Tons of CO2eq/Ton. Km) of transporting the product p, from the plant m, to the warehouse v, at period t for scenario b.

$fc_{TW_{t,b,k}}$ & $fe_{TW_{t,b,k}}$: Respectively, the annual fixed cost in ($) (GHG emissions in Tons of CO2eq) of transporting privately products, from FC's warehouses to the customer zone k, at period t for scenario b.

$fc_{TV_{t,b,k}}$ & $fe_{TV_{t,b,k}}$: Respectively, the annual fixed cost in ($) (GHG emissions in Tons of CO2eq) of transporting privately products, from 3PL's warehouses to the customer zone k, at period t for scenario b.

$vc_{T_{tbpwk}}$: Variable cost in (\$/Ton of product p) of transporting privately the product p, from the warehouse w, to the customer zone k, at period t for scenario b.

$vc_{T_{tbpvk}}$: Variable cost in (\$/Ton of product p) of transporting privately the product p, from the warehouse v, to the customer zone k, at period t for scenario b.

$c_{T^{3PL}_{tbpwk}}$ & $e_{T^{3PL}_{tbpwk}}$: Respectively, the outsourcing cost in (\$/Ton of product p) (GHG emissions in Tons of CO2eq/Ton. Km) of transporting the product p, from the warehouse w, to the customer zone k, at period t for scenario b.

$c_{T^{3PL}_{tbpvk}}$ & $e_{T^{3PL}_{tbpvk}}$: Respectively, the outsourcing cost in (\$/Ton of product p) (GHG emissions in Tons of CO2eq/Ton. Km) of transporting the product p, from the warehouse v, to the customer zone k, at period t for scenario b.

$fc_{TR_{tbiw}}$ & $fe_{TR_{tbiw}}$: Respectively, the annual fixed cost in (\$) (GHG emissions in Tons of CO2eq) of transporting privately the returned products, from the distribution segment i to the FC's hybrid warehouse w, at period t for scenario b.

$fc_{TR_{tbiu}}$ & $fe_{TR_{tbiu}}$: Respectively, the annual fixed cost in (\$) (GHG emissions in Tons of CO2eq) of transporting privately the returned products, from the distribution segment i to the 3PL's collection center u, at period t for scenario b.

$vc_{TR_{tbpkw}}$: Variable cost in (\$/Ton of returned product p) of transporting privately the returned product p, from the customer zone k to the hybrid warehouse w, at period t for scenario b.

$vc_{TR_{tbpku}}$: Variable cost in (\$/Ton of returned product p) of transporting privately the returned product p, from the customer zone k to the collection center u, to at period t for scenario b.

$c_{TR^{3PL}_{tbpkw}}$ & $e_{TR^{3PL}_{tbpkw}}$: Respectively, the outsourcing cost in (\$/Ton of returned product p) (GHG emissions in Tons of CO2eq/Ton. Km) of transporting the returned product p, from customer zone k to the hybrid warehouse w, at period t for scenario b.

$c_{TR^{3PL}_{tbpku}}$ & $e_{TR^{3PL}_{tbpku}}$: Respectively, the outsourcing cost in (\$/Ton of returned product p) (GHG emissions in Tons of CO2eq/Ton. Km) of transporting the returned product p, from customer zone k to the collection center u, at period t for scenario b.

$fc_{THW_{tbm}}$ & $fe_{THW_{tbm}}$: Respectively, the annual fixed cost in (\$) (GHG emissions in Tons of CO2eq) of transporting privately the recoverable products, from hybrid warehouses to the plant m, at period t for scenario b.

$fc_{TU_{tbm}}$ & $fe_{TU_{tbm}}$: Respectively, the annual fixed cost in ($) (GHG emissions in Tons of CO2eq) of transporting privately the recoverable products, from collection centers to the plant m, at period t for scenario b.

$vc_{THW_{tbpwm}}$: Variable cost in ($/Ton of returned product p) of transporting privately the recoverable product p, from the hybrid warehouse w, to the plant m, at period t for scenario b.

$vc_{TU_{tbpum}}$: Variable cost in ($/Ton of returned product p) of transporting privately the recoverable product p, from the collection center u, to the plant m, at period t for scenario b.

$c_{TWH^{3PL}_{tbpwm}}$ & $e_{TWH^{3PL}_{tbpwm}}$: Respectively, the outsourcing cost in ($/Ton of returned product p) (GHG emissions in Tons of CO2eq/Ton. Km) of transporting the recoverable product p, from the hybrid warehouse w to the plant m, at period t for scenario b.

$c_{TU^{3PL}_{tbpum}}$ & $e_{TU^{3PL}_{tbpum}}$: Respectively, the outsourcing cost in ($/Ton of returned product p) (GHG emissions in Tons of CO2eq/Ton. Km) of transporting the recoverable product p, from the collection center u to the plant m, at period t for scenario b.

$fc_{TU_{tbz}}$ & $fe_{TU_{tbz}}$: Respectively, the annual fixed cost in ($) (GHG emissions in Tons of CO2eq) of transporting privately the unrecoverable products, from collection centers to the 3PL's disposal center z, at period t for scenario b.

$fc_{THW_{tbz}}$ & $fe_{THW_{tbz}}$: Respectively, the annual fixed cost in ($) (GHG emissions in Tons of CO2eq) of transporting privately the unrecoverable products, from hybrid warehouses to the 3PL's disposal center z, at period t for scenario b.

$vc_{THW_{tbpwz}}$: Variable cost in ($/Ton of returned product p) of transporting privately the unrecoverable product p, from the hybrid warehouse w, to the disposal center z, at period t for scenario b.

$vc_{TU_{tbpuz}}$: Variable cost in ($/Ton of returned product p) of transporting privately the unrecoverable product p, from the collection center u, to the disposal center z, at period t for scenario b.

$c_{TWH^{3PL}_{tbpwz}}$ & $e_{TWH^{3PL}_{tbpwz}}$: Respectively, the outsourcing cost in ($/Ton of returned product p) (GHG emissions in Tons of CO2eq/Ton. Km) of transporting the unrecoverable product p, from the hybrid warehouse w to the disposal center z, at period t for scenario b.

$c_{TU^{3PL}_{tbpuz}}$ & $e_{TU^{3PL}_{tbpuz}}$: Respectively, the outsourcing cost in ($/Ton of returned product p) (GHG emissions in Tons of CO2eq/Ton. Km) of transporting the unrecoverable product p, from the collection center u to the disposal center z, at period t for scenario b.

$fc_{W_{tbw}}$ & $fe_{W_{tbw}}$: Respectively, the annual fixed cost in ($) (GHG emissions in Tons of CO2eq) of warehousing privately the products, in the warehouse w, at period t for scenario b.

$vc_{W_{tbpw}}$: Variable GHG emissions in (Tons of CO2eq/Ton of product) of warehousing privately the product p, in the warehouse w, at period t for scenario b.

$c^{3PL}_{V_{tbpv}}$ & $e^{3PL}_{V_{tbpv}}$: Respectively, the outsourcing cost in ($/Ton of product p) (GHG emissions in Tons of CO2eq/Ton of product) of warehousing the product p, in the warehouse v, at period t for scenario b.

$fc_{HW_{tbw}}$ & $fe_{HW_{tbw}}$: Respectively, the annual fixed cost in ($) (GHG emissions in Tons of CO2eq) of reprocessing privately the returned products, in the hybrid warehouse w, at period t for scenario b.

$vc_{HW_{tbpw}}$: Variable cost in ($/Ton of returned product p) of reprocessing privately the returned product p, in the hybrid warehouse w, at period t for scenario b.

$c^{3PL}_{U_{tbpu}}$ & $e^{3PL}_{U_{tbpu}}$: Respectively, the outsourcing cost in ($/Ton of returned product p) (GHG emissions in Tons of CO2eq/Ton. Km) of reprocessing the returned product p, in the collection center u, at period t for scenario b.

$c^{3PL}_{Z_{tbz}}$ & $e^{3PL}_{Z_{tbz}}$: Respectively, the outsourcing cost in ($/Ton of returned product p) (GHG emissions in Tons of CO2eq/Ton. Km) to dispose of the returned product p, in the 3PL's center z, at period t for scenario b.

D_{tbpk} : Demand of product of customer k, at period t for scenario b.

R_{tbpk} : Return of product from customer k, at period t for scenario b (see the table **2.3**)

eD_{bp} : Average fraction of returned product $p \in P$ which is considered as an unrecoverable (scrapped) product, and has to be shipped to disposal centers, for a scenario b, whatever the period

S_{tbpsm} : Expected annual units of supply s required to make the product p in the plant m, at period t, for scenario b.

$CapM_{tbp}$: Expected annual capacity of manufacturing the product p, at period t, for scenario b. It depends on the expected annual demand.

$CapW_{tbpw}$: Subscribed capacity of warehousing the product p, in the warehouse w, at period t, for scenario b.

$CapR_{tbpw}$: Expected annual returns of product p to be reprocessed in the hybrid warehouse w, at period t, for scenario b.

$CapR_{tbpu}$: Expected annual returns of product p to be reprocessed in the collection center u, at period t, for scenario b.

$CapD_{tbz}$: Subscribed capacity to dispose of unrecoverable products, in the disposal center z, at period t, for scenario b.

The two objective functions are subject to five types of constraints:

** Constraint flows (3-8); within any facility, the number of inputs is equal to the number of output.

** Capacity constraints (9-15); each facility should respect the annual subscribed capacity, before planned.

** Opening constraints (16-20); no warehousing or reprocessing operation is privately performed in a facility not open.

** Installation constraints (21-23); no product delivery is made to a non-open facility.

** Non-negative Integer (discrete products) & Binary constraints (strategic decision: 0 or 1) (24-25).

** *Flow constraints:*

$$\sum_{m}(q_{tbpmw} + q_{tbpmv}) = \sum_{k}(q_{tbpwk} + q_{tbpvk}); \forall t, b, p, w, v \quad (3)$$

$$\sum_{w} q_{tbpwk} + \sum_{v} q_{tbpvk} = D_{tbpk}; \forall t, b, p, k \quad (4)$$

$$\sum_{w} q_{tbpkw} + \sum_{u} q_{tbpku} = R_{tbpk}; \forall t, b, p, k \quad (5)$$

$$\sum_{w,z} q_{tbpwz} + \sum_{u,z} q_{tbpuz} = eD_{bp} . \sum_{k} R_{tbpk}; \forall t,b,p \quad (6)$$

$$\sum_{w,m} q_{tbpwm} + \sum_{u,m} q_{tbpum} = (1 - eD_{bp}) . \sum_{k} R_{tbpk}; \forall t,b,p \quad (7)$$

$$\sum_{w} q_{tbpwm} + \sum_{u} q_{tbpum} = \kappa_{pm} . (1 - eD_{bp}) . \sum_{k} R_{tbpk}; \forall t,b,p,m \quad (8)$$

** *Capacity constraints*:

$$q_{tbpsnm} \leq \lambda_s S_{tbpsm}; \forall t,b,p,s,n \quad (9)$$

$$\sum_{w} q_{tbpmw} + \sum_{v} q_{tbpmv} \leq \kappa_{pm} . CapM_{tbp}; \forall t,b,p,m \quad (10)$$

$$\sum_{m} q_{tbpmw} \leq ITR_p CapW_{tbpw}; \forall t,b,p,w \quad (11)$$

$$\sum_{m} q_{tbpmv} \leq ITR_p CapW_{tbpv}; \forall t,b,p,v \quad (12)$$

$$\sum_{k} q_{tbpkw} \leq CapR_{tbpw}; \forall t,b,p,w \quad (13)$$

$$\sum_{k} q_{tbpku} \leq CapR_{tbpu}; \forall t,b,p,u \quad (14)$$

$$\sum_{p,w} q_{tbpwz} + \sum_{p,u} q_{tbpuz} \leq CapD_{tbz}; \forall t,b,z \quad (15)$$

** *Opening constraints of warehouses:*

L is a very large number

$$q_{tbpmw} \leq L.y_w; \forall t,b,p,m,w \quad (16)$$

$$q_{tbpwk} \leq L.y_w; \forall t,b,p,k,w \quad (17)$$

$$q_{tbpkw} \leq L.Y_w; \forall t,b,p,k,w \quad (18)$$

$$q_{tbpwm} \leq L.Y_w; \forall t,b,p,m,w \quad (19)$$

$$q_{tbpwz} \leq L.Y_w; \forall t,b,p,z,w \quad (20)$$

** *Installation constraints:*

Transportation to warehouses and to hybrid warehouses is possible only if they are opened, & Opening the warehouses as hybrid facilities is possible, if they were already opened as conventional facilities:

$$x_w \leq y_w; \forall w \quad (21)$$

$$x_{iw} \leq Y_w; \forall i,w \quad (22)$$

$$x_{iw} \leq Y_w; \forall i,w \quad (23)$$

** *Non-negative Integer, & Binary constraints:*

$$x_{sm}, x_w, x_v, x_{Wk}, x_{Vk}, x_{iw}, x_{iu}, \\ x_{HWm}, x_{Um}, x_{HWz}, x_{Uz}, y_w, Y_w \in \{0,1\} \\ \forall p,s,m,w,v,i,k,u,z \quad (24)$$

$$q_{tbpsnm}, q_{tbpmw}, q_{tbpmv}, q_{tbpwk}, \\ q_{tbpvk}, q_{tbpkw}, q_{tbpku}, q_{tbpwm}, \\ q_{tbpum}, q_{tbpwz}, q_{tbpuz} \quad (25)$$

are non-negative integer numbers

$\forall t,b,s,p,n,m,w,v,k,u,z\ v$

Table 2.4

Example of a stochastic plan based on scenarios approach

Stochastic Parameter	linguistic expression of the trend	Trend over time of the parameter within the scenario b (1 to 5)					Interpretation of linguistic expressions
		b=1	*b*=2	*b*=3	*b*=4	*b*=5	
Demand of product *p*=1	L, M	M	L	L	L	L	L = Decrease of 5% of the last annual demand
Demand of product *p*=2	L, M, H	L	L	M	H	H	M = Increase of 3% of the last annual demand
Demand of product *p*=3	L, M, H	L	L	M	H	H	H = Increase of 7% of the last annual demand
Rate of returns p1	L, M, H	L	L	M	H	H	L =2.5% of the current annual demand
Rate of returns p2	L, M, H	L	L	M	H	H	M = 5% of the current annual demand
Rate of returns p3	M, H	M	M	M	H	H	H = 7.5% of the current annual demand
Unrecoverable fraction of product returns $eD_{b,p}$	L, M, H	L	L	M	p2: M p1 & p3:H	H	L (Lp1= 5%; Lp2=6%; Lp3=7%); M (Mp1= 10%; Mp2=12.5%; Mp3=15%) H (Hp1=15%; Hp2=17.5%; Hp3=20%).
Unit variable of Transport	L, M, H	H	M	M	M	L	L= + 0,8%; M= + 3,5%; H= + 5,5% of the last annual unit cost
Unit variable of warehousing	M, H	H	M	M	M	M	M= + 3%, H= + 4% of the last annual unit cost
Unit variable of reprocessing	L, M, H	H	M	M	M	L	L= + 2,5%; M= + 3,5%; H= + 4,5% of the last annual unit cost
Marginal Probabilities $prob_{period,scenario}$ =	$prob_{1b}$	.075	.250	.350	.250	.075	Transition probabilities' matrix 5 x 5
	$prob_{2b}$	.202	.190	.178	.231	.199	$P = \left(\pi_{bi,bj}\right) = \begin{pmatrix} .300 & .275 & .083 & .184 & .158 \\ .252 & .230 & .128 & .209 & .181 \\ .136 & .149 & .247 & .256 & .212 \\ .209 & .180 & .170 & .233 & .208 \\ .227 & .191 & .149 & .227 & .206 \end{pmatrix}$
	$prob_{3b}$	.226	.205	.154	.221	.193	
	$prob_{4b}$	.231	.209	.150	.219	.191	
	$prob_{5b}$	.232	.210	.149	.219	.191	$\mathbf{prob_{tb} = prob_{1b} . P^{t-1}}$
	$prob_{6b}$	.232	.210	.148	.219	.191	(Chapman-Kolmogorov)

N.B. Five most probable scenarios (b=1 to 5) are extracted from 17 496 possible scenarios. H= high; M= medium; L= low.

Table 2.5

Freight transportation costs expressions:

$$Z_1 = \left\{ \begin{array}{l} \sum_{t,b,s,m} prob_{tb}(1+h)^t \left\{ fc_{T_{tbsm}} \right\} x_{sm} \\ + \sum_{t,b,p,s,n,m} prob_{tb} \left\{ weight_s \delta_{nm} vc_{T_{tbsnm}} \right\} x_{sm} q_{tbpsnm} \\ + \sum_{t,b,p,s,n,m} prob_{tb} \left\{ \begin{array}{l} weight_s \delta_{nm} \\ .(1-x_{sm}) c^{3PL}_{T_{tbsnm}} \end{array} \right\} q_{tbpsnm} \end{array} \right\} \quad (1.1)$$

$$Z_1 = \left\{ \begin{array}{l} \sum_{t,b,w} prob_{tb} \left\{ (1+h)^t fc_{T_{tbw}} \right\} x_w + \sum_{t,b,v} prob_{tb} \left\{ (1+h)^t fc_{T_v} \right\} x_v \\ + \sum_{t,b,p,m,w} prob_{tb} \left\{ weight_p \delta_{mw} vc_{T_{tbpmw}} \right\} x_w q_{tbpmw} \\ + \sum_{t,b,p,m,v} prob_{tb} \left\{ weight_p \delta_{mv} vc_{T_{tbpmv}} \right\} x_v q_{tbpmv} \\ + \sum_{t,b,p,m,w} prob_{tb} \left\{ \begin{array}{l} weight_p \delta_{mw} \\ (1-x_{pw}) c^{3PL}_{T_{tbpmw}} \end{array} \right\} q_{tbpmw} \\ + \sum_{t,b,p,m,v} prob_{tb} \left\{ \begin{array}{l} weight_p \delta_{mv} \\ (1-x_{pv}) c^{3PL}_{T_{tbpmv}} \end{array} \right\} q_{tbpmv} \end{array} \right\} \quad (1.2)$$

$$Z_3 = \left\{ \begin{array}{l} \sum_{t,b,k} prob_{tb}(1+h)^t \left\{ fc_{TW_k} \right\} x_{Wk} + \sum_{t,b,k} prob_{tb}(1+h)^t \left\{ fc_{TV_k} \right\} x_{Vk} \\ + \sum_{t,b,p,w,k} prob_{tb} \left\{ weight_p \delta_{wk} vc_{T_{tbpwk}} \right\} x_{Wk} q_{tbpwk} \\ + \sum_{t,b,p,v,k} prob_{tb} \left\{ weight_p \delta_{vk} vc_{T_{tbpvk}} \right\} x_{Vk} q_{tbpvk} \\ + \sum_{t,b,p,w,k} prob_{tb} \left\{ weight_p \delta_{wk} (1-x_{Wk}) c^{3PL}_{T_{tbpwk}} \right\} q_{tbpwk} \\ + \sum_{t,b,p,v,k} prob_{tb} \left\{ weight_p \delta_{vk} (1-x_{Vk}) c^{3PL}_{T_{tbpvk}} \right\} q_{tbpvk} \end{array} \right\} \quad (1.3)$$

$$Z_4 = \left\{ \begin{array}{l} \sum_{t,b,i,w} prob_{tb}(1+h)^t \left\{ fc_{TR_{tbiw}} \right\} x_{iw} + \sum_{t,b,i,u} prob_{tb}(1+h)^t \left\{ fc_{TR_{tbiu}} \right\} x_{iu} \\ + \sum_{t,b,p,w,i,k} prob_{tb} \left\{ weightR_p \delta_{wk} vc_{TR_{tbpkw}} \right\} x_{iw} q_{tbpkw} \\ + \sum_{t,b,p,u,i,k} prob_{tb} \left\{ weightR_p \delta_{ku} vc_{TR_{tbpku}} \right\} x_{iu} q_{tbpku} \\ + \sum_{t,b,p,w,i,k} prob_{tb} \left\{ \begin{array}{l} weightR_p \delta_{wk}.(1-x_{iw}) \\ .c^{3PL}_{TR_{tbpkw}} \end{array} \right\} q_{tbpkw} \\ + \sum_{t,b,p,u,i,k} prob_{tb} \left\{ \begin{array}{l} weightR_p \delta_{ku}.(1-x_{iu}) \\ .c^{3PL}_{TR_{tbpku}} \end{array} \right\} q_{tbpku} \end{array} \right\} \quad (1.4)$$

$$Z_5 = \left\{ \begin{array}{l} \sum_{t,b,m} prob_{tb}(1+h)^t \left\{ fc_{THW_{tbm}} \right\} x_{HWm} + \sum_{t,b,m} prob_{tb}(1+h)^t \left\{ fc_{TU_{tbm}} \right\} x_{Um} \\ + \sum_{t,b,p,m,w} prob_{tb} \left\{ weightR_p \delta_{mw} vc_{T_{tbpwm}} \right\} x_{HWm} q_{tbpwm} \\ + \sum_{t,b,p,m,u} prob_{tb} \left\{ weightR_p \delta_{mu} vc_{T_{tbpum}} \right\} x_{Um} q_{tbpum} \\ + \sum_{t,b,p,m,w} prob_{tb} \left\{ \begin{array}{l} weightR_p \delta_{mw} \\ .(1-x_{HWm}) c^{3PL}_{T_{tbpwm}} \end{array} \right\} q_{tbpwm} \\ + \sum_{t,b,p,m,u} prob_{tb} \left\{ \begin{array}{l} weightR_p \delta_{mu} \\ .(1-x_{Um}) c^{3PL}_{T_{tbpum}} \end{array} \right\} q_{tbpum} \end{array} \right\} \quad (1.5)$$

$$Z_6 = \left\{ \begin{array}{l} \sum_{t,b,z} prob_{tb}(1+h)^t \left\{ fc_{THW_{tbz}} \right\} x_{HWz} + \sum_{t,b,z} prob_{tb}(1+h)^t \left\{ fc_{TU_{tbz}} \right\} x_{Uz} \\ + \sum_{t,b,p,w,z} prob_{tb} \left\{ weightR_p \delta_{wz} vc_{TR_{tbpzw}} \right\} x_{HWz} q_{tbpwz} \\ + \sum_{t,b,p,u,z} prob_{tb} \left\{ weightR_p \delta_{uz} vc_{TR_{tbpzu}} \right\} x_{Uz} q_{tbpuz} \\ + \sum_{t,b,p,w,z} prob_{tb} \left\{ weightR_p \delta_{wz} (1-x_{HWz}) c^{3PL}_{T_{tbpwz}} \right\} q_{tbpwz} \\ + \sum_{t,b,p,u,z} prob_{tb} \left\{ weightR_p \delta_{uz} (1-x_{Uz}) c^{3PL}_{T_{tbpuz}} \right\} q_{tbpuz} \end{array} \right\} \quad (1.6)$$

Table 2.6

Warehousing, reprocessing, and disposal costs expressions:

$Z_7 = \left\{ \begin{array}{l} \sum_{t,b,w} prob_{tb} (1+h)^t \left\{ fc_{W_{tbw}} \right\} y_w \\ + \sum_{t,b,p,m,w} prob_{tb} vc_{W_{tbpw}} q_{tbpmw} \\ + \sum_{t,b,p,m,v} prob_{tb} c^{3PL}_{V_{tbpv}} q_{tbpmv} \end{array} \right\}$	(1.7)
$Z_8 = \left\{ \begin{array}{l} \sum_{t,b,w} prob_{tb} (1+h)^t \left\{ fc_{HW_{tbw}} \right\} Y_w \\ + \sum_{t,b,p,k,w} prob_{tb} vc_{HW_{tbpw}} q_{tbpkw} \\ + \sum_{t,b,p,k,u} prob_{tb} c^{3PL}_{U_{tbpu}} q_{tbpku} \end{array} \right\}$	(1.8)
$Z_9 = \left\{ \begin{array}{l} \sum_{t,b,p,w,z} prob_{tb} c^{3PL}_{Z_{tbz}} q_{tbpwz} \\ + \sum_{t,b,p,u,z} prob_{tb} c^{3PL}_{Z_{tbz}} q_{tbpuz} \end{array} \right\}$	(1.9)

Table 2.7

GHG emissions' expressions (Scope1 & Scope2) :

$$C_1 = \qquad (2.1)$$

$$\left\{\begin{array}{l} \sum\limits_{t,b,s,m} prob_{tb}\{fe_{T_{tbsm}}\}x_{sm} \\ + \sum\limits_{t,b,w} prob_{tb}\{fe_{T_{tbw}}\}x_{w} + \sum\limits_{t,b,v} prob_{tb}\{fe_{T_{tbv}}\}x_{v} \\ + \sum\limits_{t,b,k} prob_{tb}\{fe_{TW_{tbk}}\}x_{Wk} + \sum\limits_{t,b,k} prob_{tb}\{fe_{TV_{tbk}}\}x_{Vk} \\ + \sum\limits_{t,b,i,w} prob_{tb}\{fe_{TR_{tbiw}}\}x_{iw} + \sum\limits_{t,b,i,u} prob_{tb}\{fe_{TR_{tbiu}}\}x_{iu} \\ + \sum\limits_{t,b,m} prob_{tb}\{fe_{THW_{tbm}}\}x_{HWm} + \sum\limits_{t,b,m} prob_{tb}\{fe_{TU_{tbm}}\}x_{Um} \\ + \sum\limits_{t,b,z} prob_{tb}\{fe_{THW_{tbz}}\}x_{HWz} + \sum\limits_{t,b,z} prob_{tb}\{fe_{TU_{tbz}}\}x_{Uz} \end{array}\right\} +$$

$$\left\{\begin{array}{l} \sum\limits_{t,b,p,s,n,m} prob_{tb}\left\{\begin{array}{l} weightS_{ps}\delta_{nm} \\ .ve_{T_{snm}} \end{array}\right\}x_{sm}q_{tbpnm} \\ + \sum\limits_{t,b,p,m,w} prob_{tb}\left\{\begin{array}{l} weight_{p}\delta_{mw} \\ .ve_{T_{pmw}} \end{array}\right\}x_{w}q_{tbpmw} + \sum\limits_{t,b,p,m,v} prob_{tb}\left\{\begin{array}{l} weight_{p}\delta_{mv} \\ .ve_{T_{pmv}} \end{array}\right\}x_{v}q_{tbpmv} \\ + \sum\limits_{t,b,p,w,k} prob_{tb}\left\{\begin{array}{l} weight_{p}\delta_{wk} \\ .ve_{T_{pwk}} \end{array}\right\}x_{Wk}q_{tbpwk} + \sum\limits_{t,b,p,v,k} prob_{tb}\left\{\begin{array}{l} weight_{p}\delta_{vk} \\ .ve_{T_{pvk}} \end{array}\right\}x_{Vk}q_{tbpvk} \\ + \sum\limits_{t,b,p,w,i,k} prob_{tb}\left\{\begin{array}{l} weightR_{p}\delta_{wk} \\ .ve_{TR_{pwk}} \end{array}\right\}x_{iw}q_{tbpkw} + \sum\limits_{t,b,p,u,i,k} prob_{tb}\left\{\begin{array}{l} weightR_{p}\delta_{ku} \\ .ve_{TR_{pku}} \end{array}\right\}x_{iu}q_{tbpku} \\ + \sum\limits_{t,b,p,m,w} prob_{tb}\left\{\begin{array}{l} weightR_{p}\delta_{mw} \\ .ve_{THW_{pwm}} \end{array}\right\}x_{HWm}q_{tbpwm} \\ + \sum\limits_{t,b,p,m,u} prob_{tb}\left\{\begin{array}{l} weightR_{p}\delta_{mu} \\ .ve_{TU_{pum}} \end{array}\right\}x_{Um}q_{tbpum} \\ + \sum\limits_{t,b,p,w,z} prob_{tb}\left\{\begin{array}{l} weightR_{p}\delta_{wz} \\ .ve_{TH_{pwz}} \end{array}\right\}x_{HWz}q_{tbpwz} + \sum\limits_{t,b,p,u,z} prob_{tb}\left\{\begin{array}{l} weightR_{p}\delta_{uz} \\ .ve_{TU_{puz}} \end{array}\right\}x_{Uz}q_{tbpuz} \end{array}\right\}$$

$$C_2 = \left\{\begin{array}{l} \sum\limits_{t,b,p,w} prob_{tb}\{fe_{W_p}\}y_{w} + \sum\limits_{t,b,p,m,w} prob_{tb}ve_{W_p}\,q_{tbpmw} \\ + \sum\limits_{t,b,p,w} prob_{tb}\{fe_{HW_p}\}Y_{w} + \sum\limits_{t,b,p,k,w} prob_{tb}ve_{W_p}\,q_{tbpkw} \end{array}\right\} \qquad (2.2)$$

Table 2.8

GHG emissions’ expressions (Scope3):

$$C_3 = \tag{2.3}$$

$$\sum_{t,b,p,s,n,m} prob_{tb} \begin{Bmatrix} weight_{ps}\delta_{nm} \\ .(1-x_{sm})e^{3PL}_{T_{snm}} \end{Bmatrix} q_{tbsnm} + \begin{Bmatrix} \sum_{t,b,p,m,v} prob_{tb} \begin{Bmatrix} weight_{p}\delta_{mv} \\ .(1-x_{v})e^{3PL}_{T_{pmv}} \end{Bmatrix} q_{tbpmv} \\ + \sum_{t,b,p,m,w} prob_{tb} \begin{Bmatrix} weight_{p}\delta_{mw} \\ .(1-x_{w})e^{3PL}_{T_{pmw}} \end{Bmatrix} q_{tbpmw} \end{Bmatrix}$$

$$+ \begin{Bmatrix} \sum_{t,b,p,w,k} prob_{tb} \begin{Bmatrix} weight_{p}\delta_{wk} \\ .(1-x_{Wk})e^{3PL}_{T_{pwk}} \end{Bmatrix} q_{tbpwk} \\ + \sum_{t,b,p,v,k} prob_{tb} \begin{Bmatrix} weight_{p}\delta_{vk} \\ .(1-x_{Vk})e^{3PL}_{T_{pvk}} \end{Bmatrix} q_{tbpvk} \end{Bmatrix} + \begin{Bmatrix} \sum_{t,b,p,w,i,k} prob_{tb} \begin{Bmatrix} weightR_{p}\delta_{wk} \\ .(1-x_{iw})e^{3PL}_{T_{pwk}} \end{Bmatrix} q_{tbpkw} \\ + \sum_{t,b,p,u,i,k} prob_{tb} \begin{Bmatrix} weightR_{p}\delta_{uk} \\ .(1-x_{iu})e^{3PL}_{T_{puk}} \end{Bmatrix} q_{tbpku} \end{Bmatrix}$$

$$+ \begin{Bmatrix} \sum_{t,b,p,m,w} prob_{tb} \begin{Bmatrix} weightR_{p}\delta_{mw} \\ .(1-x_{HWm})e^{3PL}_{T_{pmw}} \end{Bmatrix} q_{tbpwm} \\ + \sum_{t,b,p,m,u} prob_{tb} \begin{Bmatrix} weightR_{p}\delta_{mu} \\ .(1-x_{Um})e^{3PL}_{T_{pmu}} \end{Bmatrix} q_{tbpum} \end{Bmatrix} + \begin{Bmatrix} \sum_{t,b,p,w,z} prob_{tb} \begin{Bmatrix} weightR_{p}\delta_{wz} \\ .(1-x_{HWz})e^{3PL}_{T_{pwz}} \end{Bmatrix} q_{tbpwz} \\ + \sum_{t,b,p,u,z} prob_{tb} \begin{Bmatrix} weightR_{p}\delta_{uz} \\ .(1-x_{Uz})e^{3PL}_{T_{puz}} \end{Bmatrix} q_{tbpuz} \end{Bmatrix}$$

$$+ \sum_{t,b,p,w,z} prob_{tb} e^{3PL}_{Z_{pz}} q_{tbpwz} + \sum_{t,b,p,u,z} prob_{tb} e^{3PL}_{Z_{pz}} q_{tbpuz}$$

2.4.2. *Solving approach: Epsilon-Constraint algorithm*

The presence of two objectives in our design SC network problem gives rise to a set of optimal solutions, known as Pareto-optimal solutions. Each solution represents an optimal SC configuration, which is characterized by a global logistics cost, a global GHG emissions amount, and sub sets of strategic and tactical decision variables which determine which logistics activities should be outsourced, and which ones should be in-sourced.

Practically, there exist two categories of methods and algorithms for solving multi-objective optimization problems (Shukla & Deb, 2007):

- Classical methods which follow some mathematical principles such as parametrized objectives sum (Cohon, 1978), or epsilon-constraint method (Mavrotas, 2009), and perform repeated applications to find a set of Pareto-optimal solutions, and
- Non-classical methods which follow some natural or physical principles, such as evolutionary algorithms (Bäck *et al.*1997), and perform just a single simulation run to find multiple Pareto-optimal.

Convergence and diversity are two conflicting criteria which should be balanced in trying to generate a representative set of the Pareto optimal solutions (Deb *et al.* 2006). If the classical methods allow ensuring the convergence criterion, they are relatively limited in ensuring the diversity of solutions, which depends on the desired number of solutions N_{Pareto}.

We suggest in this paper an algorithm based on epsilon constraint method, to generate a dozens of non-dominant solutions, and we intend in the future improving the diversity, and the time resolution through evolutionary methods.

Start

**Initialization:

- Set the programming model with its parameters, objective functions *OBJ1* (1) and *OBJ 2* (2), and the constraints (3-25);
- Initiate the Pareto optimal solutions set Γ to $\varnothing$;
- Define the number of desired Pareto optimal solutions N_{Pareto};

**Run the Primary programming model: Minimizing *OBJ1* (total logistics cost), while excluding *OBJ2* (Carbon emissions);

- Get the first solution S_1;
- Inject S_1 into *OBJ2*; and
- Consider the obtained value of *OBJ2* as the Upper Bound *UB* of the total Carbon emissions.

**Run the Secondary programming model: Minimizing *OBJ2* (Carbon emissions), while excluding *OBJ1* (total logistics cost);

- Get the N^{th}_{Patero} solution $S_{N_{Pareto}}$;

Consider the obtained minimal value of *OBJ2* as the Lower Bound *LB* of the total Carbon emissions.

- Reinitiate $\Gamma = \left\{ S_1, S_{N_{Pareto}} \right\}$;

Calculate the increment $\boldsymbol{\varepsilon_{CO2eq} = \frac{UB\text{-}LB}{N_{Pareto}}}$

For $k = 1 \text{ to } (N_{Pareto} - 1)$

Start

Run the Primary programming model: Minimizing *OBJ1* (total logistics cost), while excluding OBJ2 (Carbon emissions); with the constraints (3-25) + The Epsilon-constraint (26):

$$\mathbf{C_1 + C_2 + C_3 \leq LB + k.\varepsilon_{CO2_{eq}}} \quad \text{(26)}$$

Actualize $\Gamma = \left\{ S_1, \ldots, S_k, S_{N_{Pareto}} \right\}$

$k = k + 1$

End

End

The figure **2.4** illustrates the Pareto Front with a dozen of diverse optimal non-dominant configurations

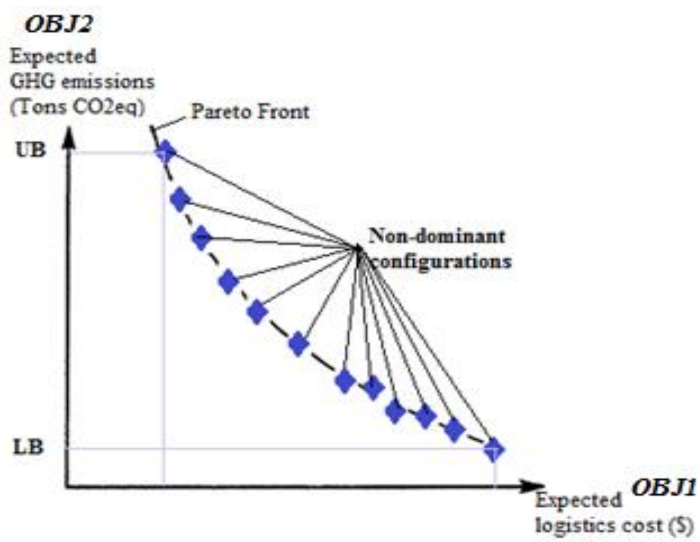


Fig. 2.4. Front Pareto of Optimal Non-dominant configurations

2.5. Discussion

In this section, we discuss some interesting managerial insights, which can be deducted from the implementation of the model.

we provide a working case study of a medium enterprise FC, which manufactures, distributes, and recover three categories of microwave ovens; the Standard products p1 (0.7 cu. Ft., 700W); the hybrid products p3 (0.9 cu. Ft., 900W), with more space and additional functions like convection and speed cooking; and the innovative products p2 (1.2 cu. Ft., 1100W), with sophisticated level of technology, such as the frequency conversion technology.

Over an interval of 6 years, and in the context of business environment uncertainties, the main objectives of the Focal Company are: 1) responding to 1/6 of the North American market in terms of micro-wave ovens, and exporting a portion of its production to European market, 2) minimizing the expected total logistics cost, and 3) minimizing the expected total GHG emissions within the global SC, before proceeding to any investment on low carbon technologies, for the purpose of counteracting the potential carbon policy imposed by governments.

The decision to outsource some or all logistics activities (transportation, warehousing, reprocessing returns of products) along its closed-loop SC should be considered in the design of its closed-loop SC.

The table **2.9** summarizes the structure of the SC, with sixty nodes.

Some logistics characteristics of the products, trailers, and containers, are specified in tables **2.10**, **2.11**, and **2.12**, to help establishing data base of the programming model.

The deterministic, the stochastic parameters, and the marginal probabilities of five most probable scenarios are prepared in a series of tables in Excel Microsoft. the code is written the data and written and the format of data is declared, both in IBM ILOG CPLEX Studio 6.1. The programming model is stochastic, quadratic bi-objective, multi-period (T=6), and multi-product (p=3). Following the algorithm based on Epsilon constraint, we desire generate **12 non-dominant solutions**. Each Pareto solution is characterized by a set of **361** strategic and **57 510** tactical variables, totalling **57 871 decision variables**. All the solutions are directly structured in Excel Microsoft tables of the data base files. The quadratic programming model may be transformed to a linear programming model by doubling the number of tactical decision variables, and appending additional constraints.

Table 2.9

The sixty nodes of the network (Ongoing case study)

Suppliers per supply category s = 1, 2, 3, et 4				Manufacturing & Remanufacturing centers	Warehousing facilities		Customers 'zones per distribution Segment i = 1, 2, 3, et 4				Reprocessing centers		Disposal centers
s = 1	2	3	4	m	w	v	i=1	2	3	4	w	u	z
6	5	2	5	2	6	5	4	4	5	4	6	6	7

Table 2.10

Number of units stacked on a standard pallet (40 " x 48 ")

	Standard product p=1	Innovative product p= 2	Hybrid product p=3
Units of Product	18	12	12
Units of Non-critical supply	527	302	508
Units of Leverage supply	196	75	111
Units of Bottleneck supply	41	53	26
Units of Strategic supply	42	21	30

Table 2.11

Logistical characteristics of three types of microwave ovens

Product	Package dimensions (cm)	Non-critical Supply (grams) (% Weight)	Bottleneck Supply (grams) (% Weight)	Leverage Supply (grams) (% Weight)	Strategic Supply (grams) (% Weight)
Standard	L: 49.6; W: 35.4; H: 29.4	375 (3.4%)	4 830 (44.0%)	1 010 (09.2%)	4 755 (43.4%)
Hybrid	L: 54.7; W: 43.0; H: 33.7	375 (2.3%)	7 465 (47.0%)	1 710 (10.8%)	6 325 (39.9%)
Innovative	L: 56.2; W: 45.0; H: 36.0	375 (4.0%)	2 125 (22.5%)	1 510 (16.0%)	5 433 (57.5%)

Table 2.12

Number of standard pallets stacked 2 high, by type of truck configurations

Container Dimension	Number of Pallets	Product 1	Non critical supply	Leverage supply	Bottleneck supply	Strategic supply
20-foot container (maritime)	20	360	10540	3920	820	840
28-foot MDV/LTL	28	504	14756	5488	1148	1176
53-foot HDV / TL	52	936	27404	10192	2132	2184
Container Dimension	Number of Pallets	Product 2	Non-critical supply	Leverage supply	Bottleneck supply	Strategic supply
20-foot container (maritime)	20	240	6040	1500	1060	420
28-foot MDV/LTL	28	336	8456	2100	1484	588
53-foot HDV / TL	52	624	15704	3900	2756	1092
Container Dimension	Number of Pallets	Product 3	Non-critical supply	Leverage supply	Bottleneck supply	Strategic supply
20-foot container (maritime)	20	240	10160	2220	520	600
28-foot MDV/LTL	28	336	14224	3108	728	840
53-foot HDV / TL	52	624	26146	5772	1352	1560

The analysis of results is made in the perspective to answer the two key questions asked in the introduction. We suggest to:

- Plot the eco efficiency curve (logistics cost versus GHG emissions) of the 12 optimal solutions, to verify the diversity criterion, and the convexity of the bi-objective function, as illustrated in the figure **2.4.**
- Calculate the total cost of each logistics activity (Transportation, warehousing, reprocessing, and disposal of) between two consecutive echelons of the SC. Separate the logistics cost of outsourcing & insourcing, and calculate the ratio of outsourcing vs the logistics cost, then compare it with the ratios published in special magazines (e.g. Langley J. Jr. & Cap Gemini)

- Do the same for GHG emissions.

Once, the three scopes of GHG emissions are determined, the focal company FC may report directly its GHG emissions, in accordance with the GHG Protocol Corporate Standard.

2.6. Conclusion

The effective integration of 3PLs within a Supply Chain (SC) goes through the determination of an optimum level of logistics outsourcing, that results in high performances. In this paper, we integrate the logistics outsourcing decisions within the green SC network design, in the context of business environment uncertainty. Following a Scenarios-based approach, we suggest a stochastic, bi-objective, multi-period, and multi-product programming model, which integrates logistics outsourcing decision in a closed-loop SC. The model can serve as an effective tool in identifying a set of optimal decarbonized SC configurations, which distinguishes the logistics activities to perform in-house from those to outsource.

The main contribution of this work may be structured in three points:

- We provide a general structure of the SC network, which captures the main SC management issues: 1) The security of supplies, to reduce the cost and ensure continuous supplies; the market segmentation, to satisfy heterogeneous requirements of different customers; and the Extended Producer Responsibility to collect and reprocess the returns of used products for the purpose of remanufacturing.
- We use the principle of first-clustering, and second-sizing, to provide a constructive model, for roughly estimating transportation costs and corresponding GHG emissions factors, of both insourcing and outsourcing. Likewise, for the warehousing, and reprocessing of used products. These models may be easily adapted, modified, and utilized to generate reliable data, required for implementing SC network programming models.
- Unlike the recent models of SC de-carbonization (Zakeri *et al.* 2015; Fareedunddin *et al.* 2015), which combine directly carbon policies and economic performance to design the SC network by minimizing one objective (e.g. the total cost), we suggest a stochastic model, which minimize

the logistics cost ($), and minimize the GHG emissions (Tons of CO_2eq), before any attempt to counteract the carbon policies by means of promised low-carbon technologies. Doing so, the Focal Company will have more visibility on the different scopes of its GHG emissions, will have outsourcing ratios for the purpose of benchmarking, and will have more flexibility to select the best SC configuration.

So, the suggested modelling and solving approaches capture the potential drawbacks (e.g. low degrees of the scope, realism, complexity, and resolution), that repel the SC network design models from the reality.

Some disadvantages and challenges can be assigned to our modelling and solving approaches, as follows:

- Taking into account the different issues of SC management, and capturing the uncertainty of some parameters increase significantly the model's size. Thereby the time of data development, is affected so much.
- Although we use special logistics reviews such as Cap Gemini consulting, and American Transportation Research Institute, and European Commission - Mobility and Transport DG –Library, to construct the computing logistics costs models and corresponding GHG emission models, very few empirical studies were find to compare economical (Facanha & Horvath, 2005), and environmental (MIT Center for Transport & Logistic) performances of logistics operations, between private operators and 3PL services providers.
- Integrating logistics outsourcing decisions in the SC network design increases the model complexity by making a quadratic the multi-objective function, thus affects the time of resolution.
- Solving the model with the algorithm based on the Epsilon-constraint approach guarantees the convergence towards Pareto optimal solutions, but the diversity of these solutions closely depends on the desired number of the solutions.

Three directions are planned for our further research:

- Integrating Logistics outsourcing decisions within the green SC network design, lead to a set of non-dominant configurations. To select the best configuration, and contrary to what could be an option such as: Respecting a certain level of GHG emissions, or considering the budget limitation before or after some low carbon technologies investment, we are developing a second mono-objective combinatory model, which considers a set of candidate low-carbon technologies to counteract the uncertain carbon pricing policies. The injection of the present Pareto solutions, in the new combinatory model will identify the best decarbonized SC configuration, which minimizes the sum of logistics cost, low-carbon technologies investment, and carbon policy cost. Thus, the optimal level of 3PL integration within the closed-loop SC network can be determined, into a two-phased stochastic model.

- Improve the quality of Pareto solution (e.g. Convergence & Diversity), by developing an evolutionary approach to efficiently solve large stochastic multi-objective programming model.
- Once the optimum level of 3PL integration within the green SC network design is determined, it would be worth to develop an integrated approach to select a 3PL service provider in the context of Sustainable SC. So, the social acceptability will be introduced, among other criteria to improve the sustainable practice between the actors and their suppliers within the SC network.

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Chapter 3:

Internal Carbon Price Impact on Logistics Outsourcing & Low Carbon Reduction Investment Decisions in a Green Supply Chain Design:

A Two-stage Stochastic Modelling Approach

Highlights:

- Logistics Outsourcing & Low Carbon investment are integrated in Supply Chain design;
- A two-stage stochastic modelling approach within a multi-period horizon is proposed;
- We synthesized the evolution of fleet size from Pareto solutions of the 1st stage model;
- We establish a Carbon stochastic price plan in the context of voluntary disclosure Carbon regime;
- 2^{d} stage model leads to identify optimal levels of 3PL integration, and Low Carbon investment.

Résumé

Dans ce chapitre, nous proposons une approche de modélisation stochastique en deux étapes pour concevoir une chaîne logistique en boucle fermée résiliente au changement climatique. Cette approche intègre à la fois la décision d'investissement en technologies sobres au carbone, et la décision d'externaliser les activités logistiques. Tout d'abord, nous donnons un bref aperçu du modèle stochastique de la première étape, qui a été abordé dans le chapitre précédent. L'implémentation de ce multi-objectif, multi-période, multi-produit, et stochastique modèle de programmation fournit un ensemble de solutions Pareto optimales, qui minimisent à la fois le total espéré du coût logistique et les émissions de Gaz à Effet de Serre GES correspondant. Deuxièmement, nous utilisons le concept de tarification interne du carbone pour établir un plan stochastique contre les politiques de carbone du gouvernement. Ensuite, nous considérons un ensemble de différentes approches préférées de réduction potentielle des émissions de carbone dans le secteur de transport de marchandises, en vue d'investissement pendant un horizon de périodes données. Troisièmement, nous proposons un modèle combinatoire stochastique contraint, pour minimiser le coût total des activités logistiques, dans un contexte de politiques de carbone aléatoires. L'injection de chaque solution Pareto dans ce modèle de deuxième étape, et sa résolution conduisent à sélectionner la configuration de la chaine logistique la plus résiliente au changement climatique. Cette configuration définit non seulement le plan d'investissement optimal, mais aussi le niveau optimal d'externalisation de la logistique.

Abstract

In this chapter, we suggest a two-stage stochastic modelling approach to design a climate change resilient closed-loop Supply Chain (SC), which integrates both low carbon investment and logistics outsourcing decisions. First, we give a brief overview of the first stage stochastic model, which has been addressed in the previous chapter. The run of this stochastic multi-objective multi-period and multi-product programming model provides a set of Pareto optimal solutions, which minimize both the total expected logistics cost and corresponding Green House Gas emissions. Second, we use the concept of internal Carbone pricing to establish a stochastic plan against government carbon policies. Then, we consider a set of prioritized potential individual Low-Carbon Reduction (LCR) approaches of freight transportation, to invest in during a horizon of given periods. Third, we suggest a constrained stochastic combinatory model, to minimize the total cost of expected logistics activities, in the context of carbon policies uncertainty. The injection of each Pareto optimal solution in this second-stage model, and the resolution lead to select the most efficient climate resilient SC configuration, which defines not only the optimal plan of LCR investment, but the optimal level of logistics outsourcing within the SC as well.

Keywords:

- Logistics Outsourcing
- Supply chain network design
- Carbon Pricing Policies
- Low carbon technologies of transportation
- Stochastic multi objective optimization

3.1. Introduction

Governments have recently submitted their Intended Nationally Determined Contributions (INDC) to Paris COP21 negotiations, to lead the world towards a low-carbon climate resilient economy. For instance, by 2030 EU promised Green House Gas (GHG) emissions mitigation of 40% below 1990 levels; US promised a reduction of 26–28 % below 2005 levels; and China promised to reduce its GHG intensity by 60–65% compared to 2005 (Lomborg, 2016). According to Grant *et al.* (2014), and Brown (2010), to foster industry sectors managing the risk of climate change related to their Supply Chains (SCs), policymakers in different jurisdictions have quite a challenge to:

- Design appropriate climate-focused policies, and/or energy policies with climate implications;
- Tighten the GHG safety and emission standards of the facilities and equipment; and
- Establish cost-effective procedures for auditing and certifying the facilities and equipment;

Huang *et al.* (2009) have reported that more than 75% of the GHG emissions in many industry sectors come from their SCs. Upstream GHG emissions are, on average, more than twice those of a Focal Company's operational emissions, which makes it critical to build climate resilience into SCs (CDP & BSR, 2016). So, reducing those indirect GHG emissions may be more cost-effective for an industrial company, than reducing its direct GHG emissions (Montoya-Torres *et al.* 2015). In Browne, *et al.* (2009), the World Economic Forum suggests thirteen effective strategies for the SCs designers, and managers to build their climate change resilient SCs, and among the most effective ones:

- Improving the network logistics planning through global optimization, and
- investing in Low Carbon Reduction (LCR) technologies, and energy efficiency to counteract carbon policies of different jurisdictions.

The integration decision of customers and suppliers in the SC network design may help Focal Companies (FCs) within the SCs to combat climate change and its impacts; face increased regulatory risks; share investment risk of low carbon technologies, and maintain high level of competitiveness (Gao & Ryan, 2014; Rosenzweig *et al.* 2003). However, according to Das *et al.* (2006), the full suppliers' integration within the SC is intriguing: On the one hand, supplier integration can lead to enhanced business performance through economies of scale and scope (Jayaram & Tan, 2010). On the other hand, interdependence may create rigidities, inflexibilities, and coordination issues that can affect social and environmental performance negatively (CDP & BSR, 2016; Wolf & Seuring, 2010).

For instance, Third-Party logistics service providers (3PLs) are companies that work with outsourcing companies to perform their logistics operations (e.g. inbound, outbound, or reverse logistics). According to the 19th annual 3PL studies of Langley & Capgemini (2013), 40% of the world logistics activities is outsourced to 3PLs, but about 30% of the 3PL users decide systematically each year to stop logistics, because the irrelevancy of their outsourcing decisions. In fact, the 3PL have the resources and capability to reach high levels of logistics efficiencies (e.g. reduction of transportation costs by 20-10%, and warehousing cost by 10-5%) (Webster & Mitra, 2007; Facanha & Horvath, 2005). However, they seem not undertake concrete sustainable initiatives vis-à-vis the energy efficiency & GHG emissions (e.g. 20 to 30% moreover than private FC's operations), and vis-à-vis the traffic congestion (e. g. more than 17% of fuel cost, because the choice of a flexible routing network strategy, rather than a point-to-point strategy for picking, and deliveries) (Evangelista *et al.* 2011; Blanco & Craig, 2009).

To conciliate the two contradictory states, Das *et al.* (2006) have theorized the existence of an optimal level of suppliers' integration within the global SC, that results in high performances. In other words, the outsourcing, and particularly logistics outsourcing is a strategic decision, and should have been considered since the SC network design or reconfiguration (Gao & Ryan, 2014; Ordoobadi, 2010).

In the literature, three approaches for dealing with logistics outsourcing may be encountered:

The first approach; the classical one, which has been recommended by Ordoobadi (2005), and consists of:

- Considering a logistics activity (i.e. transport, warehousing, reprocessing returns…) as a project;
- Raising the question whether the logistical activity is a candidate for outsourcing or not? According to several strategic criteria (Quinn & Hilmer, 1994; Prahalad & Hamel, 1990), the activity may be categorized into; 1) a high core competency, which offer the FC (e.g. Manufacturer) long-term competitive advantages, and must be kept in-house; 2) a medium core competency, which is a

somewhat marginal activity, and require more analysis to determine whether it should continue in-house or be outsourced; and 3) a low core competency, which is a peripheral activity, that may be outsourced to a selected 3PL.

- Performing an economical analysis of the logistics activity, in case of it belongs to the second category. Outsourcing and in-house costs are determined, and compared to make the logistics outsourcing decision.

The second approach has been proposed by authors such as Chiu *et al.* (2011); Jaber & Goyal, (2008); and Savaskan *et al.* (2004), and consists of:

- Considering a portion of the global SC network (i.e. inbound, outbound, or reverse logistics)
- Considering three potential configurations within the portion, in which one the FC (e.g. manufacturer), the customer/the supplier, or the 3PL leads the logistics activity to be outsourced or not.
- Constructing a mathematical model, to maximize the total profit of each configuration.
- Comparing the total profit of the configurations, and make the logistics outsourcing decision.

The third approach has been suggested by Mukhopadhyay & Setaputra, (2006), and consists of:

- Extracting an area in the SC design network (i.e. inbound, outbound, or reverse logistics)
- Considering only the configuration in which the 3PL leads the logistics activity to outsource.
- Constructing a profit-maximization model, to jointly obtain optimal policies for the FC (e.g. Manufacturer), and the 3PL, using *Stackelberg* like game theory, and where the FC acts as the leader, and the 3PL acts as the follower.

The first approach puts the decision maker between two choices; performing logistics activity in-house, or outsourcing. It considers qualitatively the strategic dimension of logistics outsourcing, but does not show the impact of the outsourcing decision on the structure of the global SC.

The second approach offers three possibilities to deal with the outsourcing problem by considering the FC; the 3PL; and the Supplier/Customer. It provides an unconstrained optimization model, to determine the optimal configuration, corresponding to the maximum total profit of the considered logistics system. As highlighted by Chiu *et al.* (2011), this approach may generate conflict of interests between the three actors, because the 'inadequate' profit repartition between them.

The third approach capture the drawback of the second approach, by utilizing the game theory to establish a win/win relationship between the FC, and the 3PL, and to define optimal policies to sustain the logistics outsourcing.

All the approaches consider the economical criterion in the logistics outsourcing problem, and forget the environmental one. While the 3PL integration optimality of Das *et al.* (2006) must be searched in the context of the global SC, the approaches are applied within extracted areas the SC. So, the separated outsourced decisions may provide suboptimal solutions to the logistics outsourcing problem. Finally, the presented approaches provide unconstrained deterministic optimization models, in stead of considering the business, and carbon policies uncertainties, which become inevitable for any global SC.

This paper is based on the very recent work of Ameknassi *et al.* (2016), who suggested a modelling approach to integrate logistics outsourcing decisions in a decarbonized SC network design problem. Their stochastic multi-objective, multi-period, and multi-product programming model is solved by an epsilon constraint method, and leads to a set of Pareto optimal configurations. Within each optimal configuration all the outsourced logistics activities (e.g. Transportation; Warehousing; and Reprocessing of returned products) can be distinguished from those that should be performed in-house. All the non-dominant solutions allow to minimize both the expected logistics cost ($), and corresponding GHG emissions (Ton CO2eq) of the closed-loop SC, before any low carbon investment.

The paper considers the set of Pareto optimal configurations as the first stage of a holistic stochastic modelling approach to design a green closed-loop SC in the context of uncertainties, and suggests a second stage, in which not only the best SC configuration is selected, but the most effective low carbon investment strategy for counteracting the policy carbon is defined as well.

The main contribution of this paper is the introduction of the internal carbon price concept in the design of the climate change resilient closed-loop SC network problem, integrating logistics outsourcing, and low carbon investment decisions, in the context of business and carbon policy uncertainties.

The remainder of this paper is organized as follows. In section 2, we provide a literature overview on; the GHG emission reporting &Carbone pricing strategies; and the Low Carbon reduction approaches in freight transportation industry. In section 3, we provide a brief overview on the first stage of stochastic modelling, which we have treated in Ameknassi *et al.* (2016). In section 4, we suggest a stochastic plan for estimating the carbon price. Before providing the second-stage programming model, it is worth, we prepare some key data required for its implementation, then we present the combinatory programming model of the second-stage of the stochastic modelling approach. We discuss some managerial insights, which can be encountered in the implementation of the suggested programming model. Finally, in the section 5 we draw the conclusion.

3.2. Literature review

Knowing its GHG emissions allows to determine to what extent, it is necessary to align with the carbon policy being imposed by governments. Being aware of available and future sober carbon technologies, allows to establish an effective investment plan, and to seek attracting investors to fund it. Finally, updating the knowledge of SC network modelling and solving techniques can integrate effectively the main concerns of SC management of the FC. Hereunder, we provide an overview of two streams of research, which are related to the subject of the present paper;

- GHG emission reporting, and Carbon pricing strategies; and
- Low Carbon reduction approaches of freight transportation.

3.2.1. GHG emission reporting & Carbon pricing

The seven GHG covered by the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol are: Carbon dioxide (CO_2); Methane (CH_4); Nitrous oxide (N_2O); Hydro-fluorocarbons (HFCs); Per-fluorocarbons (PFCs); Sulphur hexafluoride (SF_6); and Nitrogen tri-fluoride (NF_3). In this paper, we consider only the most measurable GHG emissions of: CO_2 with the reactive factor (Global Warming Potential) GWP=1; CH_4 with GWP=25; N_2O with GWP=298; and HCF, especially CH_2FCF_3 (R 134a), with GWP= 1430.

According to McKinnon & Piecyk (2011), there are basically two approaches for determining GHG emissions of logistics operations: The energy-based approach, and the activity-based approach. In the first approach, energy used in operations is recorded, and standard emission factors are employed to convert energy value into carbon equivalent emissions. In the case of energy data absence, it is possible to make a rough estimate of the default factors of GHG emissions, by applying the second approach. As an example, we provide the GHG default factors of a working work in the table **2.2** in the chapter **2**

To help companies reporting their GHG emissions, many accounting methodologies have been developed in collaboration with multiple private, public, and non-governmental organizations. We highlight WRI/WBCSD GHG Protocol, ISO 14064, IPCC guidelines, and DEFRA, and the most commonly used is the WRI/WBCSD GHG Protocol (WRI/WBCSD, 2013), which is distinguished by its universality, and adaptability to the most industrial sectors (Matisoff *et al.* 2013). It defines three "scopes" of GHG emissions:

- Scope 1 accounts for direct GHG emissions, from combustion fuels in stationary and mobile sources that are owned or controlled by the FC, and from hydrofluorocarbon (HFC) emissions during the FC's use of refrigeration and air conditioning equipment;
- Scope 2 accounts for GHG emissions from the generation of purchased electricity consumed by the FC; and
- Scope 3 accounts for other indirect GHG emissions. They are a consequence of the activities of the FC, which occur from sources not owned or controlled by the FC. For example, logistics outsourcing operations, and the transportation of purchased fuels.

In countries with existing or imminent GHG regulations, Mandatory carbon disclosure regimes (e.g. EU Emissions Trading Scheme ETS; US Environmental Protection Agency; California-Quebec Cap and Trade; Australia ETS; South Africa Carbon tax) are established, to force industrials for reporting their GHG emissions, in a standard format, such as that of the WRI/WBCSD GHG Protocol. However, voluntary carbon disclosure regimes (e.g. Carbon Disclosure Project CDP, and Global Reporting Initiative GRI) are experiencing further influence in:

- Providing investors and public with standardized GHG disclosure data, that would enable comparison across companies;
- Rewarding strong performers with reputational benefits; while
- Pressuring non-disclosers and poor performers (Knox-Hayes & Levy, 2011)

Regardless the carbon disclosure regime applied, Governments; Investors; and Businesses are recognizing that nationally-appropriate carbon pricing strategy, is the most effective way to deal with climate change, and to meet the INDCs mentioned at the beginning of the introduction, without harming the economy. (Rydge, 2015; Kossoy *et al.* 2015). In fact:

- For governments, Carbon Taxes and Emissions Trading Schemes (ETS), as part of a well-aligned package of climate change policies is an instrument to achieve the INDC, and also a source of revenue to manage the pricing mechanisms and sustainable development projects;
- Long-term investors use carbon pricing to analyze the potential impact of climate change policies on their investment portfolios, allowing them to reassess investment strategies and reallocate capital toward low-carbon or climate-safe activities; and
- Businesses use the concept of *internal carbon price* (i.e. internal carbon fee, shadow price, or carbon adder…) as a part of risk management strategy to estimate a proxy social cost of their GHG emissions. This cost seeks to reflect all types of carbon policies, that governments may take over the outlook periods relating to the realization, and the operation of new projects.

The question of choosing an internal carbon price is challenging the companies: This is a complex process involving the use of models and expert judgment.

According to CDP (2015), in countries with existing or imminent GHG regulation such as EU, companies often take the price of ETS as the principle basis for the internal validation of carbon related investments and projects. However, in countries without existing or imminent GHG regulation such as North America, all intensive capital projects with important GHG emissions, should be subject to a range of internal carbon prices, derived from the most probable scenarios, to assess their financial viability.

In this paper, we focus on the second case, in which a SC network is designed in the context of voluntary carbon disclosure regime. We will assess the financial viability of a set of potential individual low carbon technologies for freight transportation, which are subject to a range of carbon prices. The carbon prices will be derived from a stochastic plan based on seven most probable scenarios.

Hereunder, we provide a brief overview on the low carbon approaches applied in freight transportation industry.

3.2.2. Low carbon reduction approaches in freight transportation industry

In Langley & Capgemini (2013), Logistics activities account for 12% of company's revenue, and Freight transportation represents about 60% of logistics expenditure. Diesel-fueled combination tractor-trailers are the prime movers to transport most manufactured goods throughout world economies. According to Lutsey *et al.* (2014), they represent less than 2% of overall US. on-road vehicle sales and stock, but about 20% of all on-road transportation oil use and climate emissions. The average purchasing price of a new tractor is now estimated to a range between $110 000 to $125 000, and $30 000 to $50 000 for a new trailer.

Existing and emerging low carbon technologies related to tractor-trailers provide excellent opportunities to reduce the GHG emissions. That is why governments of Japan, US, Canada, China, and EU have adopted new standards to regulate the fuel efficiency of Medium & Heavy Duty Vehicles (MHDV), including the tractor-trailers' combinations (Sharpe & Muncrief, 2015).

Tractor truck manufacturers are suggesting two categories of individual technologies of achieving fuel efficiency, and important Low Carbon Reduction LCR: Powertrain technologies and Vehicle technologies. Powertrain technologies comprise Diesel engine; Transmission & Driveline technologies; and hybrid Powertrains. While Vehicle technologies comprise aerodynamics, rolling resistance, mass/weight reduction, idle reduction, and intelligent vehicles. Some technologies, such as certain aerodynamic features, automated manual transmissions, and wide-base single low-rolling resistance tires, are already available in production. The other technologies are in varying stages of development Brown *et al.* (2010), Other Complementary approaches can achieve important LCR, such as Driver training, and Intelligent transportation systems.

Generally, the low carbon technologies result in increased vehicle cost, and purchasers must weigh the additional cost against the carbon reduction that will accrue. Assuming 3 trailers per tractor, low Carbon efficiency technology package could result in LCR of about 48-56%, and cost increase of about 15-25%, with a payback in 1 – 3 years, depending on the discount rate, and the diesel price (Meszler *et al.* 2015).

The table **3.1** provides the estimate of the range of LCR that is potentially achievable with available and emerging technologies in the period 2015 to 2025, compared to a 2010 baseline, and corresponding individual costs.

In Brown (2010), the Committee to assess Fuel Economy Technologies for Medium-and-Heavy Duty Vehicles highlights that the percent (LCR_{tech}) values shown for individual technologies in the table **1** are not additive, and the LCR_{global} associated to a *N* combination of low carbon approaches (tech.1; tech.2… tech. I…tech. *N*) can be expressed by the equation (i):

$$LCR_{global} = [1-(1-y_{tech1}.LCR_{tech1}) *(1-y_{tech2}.LCR_{tech2}) *\dots*(1-y_{techN}.LCR_{techN})] \quad (i)$$

Where $y_{tech(I)}$ is a binary variable equal to 1 if the technology *tech* I is utilized, and equal to 0 otherwise?

Table 3.1

Range of % LCR & cost of individual low carbon technologies in the period 2015 to 2025, compared to a 2010 baseline (3 trailers working for one tractor). Sources: Meszler *et al.* (2015); and Brown, (2010).

Low carbon Approach (*l*)	Estimate of Cost ($ US.) $Cost_l$	% reduction of CO2eq LCR_l
(*l*=1) [5]Engine efficiency	**7 850**	**20** (**14**)
(*l*=2) [4]Transmissio efficiency	**5 100**	**7** (**4**)
(*l*=3) [6]Hybrid system	**16 000**	**10** (**30**)
(*l*=4) [1]Tractor-trailers aerodynamics	**13 800**	**11.5** (**6**)
(*l*=5) [2]Low rolling resistance tractor-trailers	**1 931**	**11** (**3**)
(*l*=6) [3]Driver training	**3 500**	**2 – 17**

N.B. The values between brackets correspond to MDV (Straight trucks & Tractor- 28 ft trailers), while others correspond to HDV (Tractor-53 ft trailers)

In the present paper, we suppose that:

- MDV are used to move goods, within a barycenter less than 500 miles, and HDV are used for more than 500miles.
- The size of fleet varies yearly according to expected demands, and returns of products.
- Three trailers are associated to each truck.
- The low carbon individual technologies are subject to a certain prioritization: 1) Aerodynamics; 2) Low rolling resistance; 3) Driver training; 4) Transmission efficiency; 4) Diesel engine efficiency; and 6) Hybridization. This prioritization will be expressed analytically in the constraints of the second-stage stochastic model.
- To facilitate the implementation of the suggested programming model, we suggest relaxing the relation (i), by the linear relation (2) as follows:

$$LCR_{global} \approx \vartheta . \sum_{l=1}^{N} y_{tech(l)} . LCR_{tech(l)} \qquad \text{(ii)}$$

Where, ϑ is a factor of linearity.

Before presenting our stochastic modelling approach in its second-stage to optimize the low carbon investment within a decarbonized SC network, which integrates logistics outsourcing decisions, we provide a short overview on the SC network design problem.

3.3. Second-stage of the Stochastic Modelling

3.3.1. Stochastic plan of carbon price

In this paper, we establish a set of seven scenarios $b' \in B'$ derived from three major trends of carbon policies (see table **3**).

These trends are:

1) *Senario1: The actuation of a social cost of carbon emissions* (Tseng & Hung, 2014; Etchart *et al.* 2012). Using the real cost of emissions based on the price on the global environmental damages from emissions, or the "social cost of carbon." A recent US. Government study concluded that an additional ton of carbon dioxide emitted in 2015 would cause $37 worth of economic damages, and the trend of this cost would be an annual increasing rate of 4.76%.

   http://news.stanford.edu/news/2015/january/emissions-social-costs-011215.html

2) *Senario2: The instauration of a carbon tax* (Nordhaus, 2007). Setting a tax designed to achieve a revenue goal for green projects. For example, a recent study by experts at Resources for the Future and the National Energy Policy Institute suggests that a carbon tax reaching about $30 per ton of CO2 by 2020 would be needed to reduce US domestic, energy-related CO2 emissions by approximately 10 %. To achieve this, the tax should rise at approximately the risk-free rate of interest (roughly 5 %) to balance the value of 18.41 $ in 2010's terms of making adjustments in the future.

   http://www.rff.org/centers/energy_and_climate_economics/Pages/Carbon_Tax_FAQs.aspx

3) *Senario3: The establishment of an Emission Trading Scheme* (Andrew, 2008). Setting a carbon price mechanism to achieve planned GHG emissions targets, in which the rate may depend on the fuel prices. The estimate Carbone price of 23.5 $/ton of CO2eq in 2015 should rise at an annual rate of 6.88 per cent (Source: World Bank Commodity Forecast Price data, June 2015).

http://knoema.fr/yxptpab/crude-oil-price-forecast-long-term-2015-to-2025-data-and-charts

For a global SC crossing many jurisdictions, the possible scenarios that may be occur are: b'1= scenario1; b'2= scenario2; b'3= scenario3; b'4= senario4 = scenario1 + scenario2; b'5= scenario 5 = senario2 + senario3; b'6= senario6 = senario1 + scenario3; and b'7= senario7= senario1 + scenario2 + scenario3.

The dynamic change between scenarios $b' \in B'$ needs to be approached by a transition matrix, which "ideally" should be constant in time (Meyn & Tweedie, 1996). We basically consider the dynamic change of scenarios following a Markov Chain with one constant matrix of transition. So, the marginal probabilities of scenarios at a given period *t* may be determined by the formula Chapman-Kolmogorov (Ross, 2009). If not so, the stochastic carbon plan should include more than one transition matrix switching between themselves (Horn, 1975)

In the table **3.2**, we suggest the stochastic plan of carbon pricing with the seven scenarios, the initial carbon prices $c_{0,b'}^{CO_2}$, the annual growth rate of carbon price $\theta_{b'}$, the constant matrix of transition *P*, and the marginal probabilities of scenarios.

Table 3.2

Carbon price scenarios and corresponding marginal probabilities

Scenario b'	$c_{0,b'}^{CO_2}$: Started CO2eq price (US \$/Ton CO_{2Eq})	Annual growth rate $\theta_{b'}$ % of carbon price
b' = (1)	**37.00**	**4.26**
b' = (2)	**23.50**	**6.88**
b' = (3)	**23.50**	**5.26**
b' = (4) = (1) + (2)	**30.25**	**5.60**
b' = (5) = (2) + (3)	**23.50**	**5.80**
b' = (6) = (1) + (3)	**30.25**	**4.60**
b' = (7) = (1) + (2) + (3)	**28.00**	**5.20**

Transient probabilities matrix *P*

$$P = \begin{pmatrix} .046 & .092 & .138 & .129 & .202 & .170 & .223 \\ .015 & .145 & .131 & .152 & .211 & .139 & .207 \\ .014 & .070 & .197 & .081 & .219 & .202 & .217 \\ .046 & .153 & .076 & .183 & .204 & .115 & .223 \\ .023 & .129 & .144 & .146 & .160 & .159 & .239 \\ .014 & .085 & .172 & .096 & .225 & .180 & .228 \\ .023 & .159 & .080 & .178 & .223 & .098 & .239 \end{pmatrix}$$

Marginal probabilities $\mathbf{prob_{tb'}} = \mathbf{prob_{1b'}} . \mathbf{P^{t-1}}$

T (year)	b'=1	b'=2	b'=3	b'=4	b'=5	b'=6	b'=7
1	.050	.200	.300	.050	.150	.100	.150
2	.020	.114	.147	.129	.208	.159	.223
3	.023	.124	.132	.141	.205	.147	.228
4	.023	.126	.129	.143	.205	.145	.228
5	.023	.126	.129	.143	.205	.145	.228
6	.023	.126	.129	.143	.205	.145	.228

3.3.2. Key data of the second-stage model

Before providing the second-stage programming model, it is worth to prepare some key data required for its implementation.

The first-stage programming model provide N_{Pareto} Solutions. Each solution Sj comprises:

Obj1 (expected total logistics cost); Obj2 (expected total GHG emissions);

Binary decisions of outsourcing transportation, opening warehouses, and opening warehouses as hybrid distribution centres; and Tactical decisions, which are the quantity of moved products within the closed-loop SC.

The second-stage model needs essentially two data, to be synthesized from of the result of first stage model implementation:

- The variation of number of trucks between two consecutive periods t-1, and t, which are assigned to serve a given destination within the SC network, and
- The optimum expected GHG emissions per period t of this transport configuration.

*** Concerning the number of trucks; the constructive models provided by Ameknassi (2016) lead to estimate roughly the logistics cost, and corresponding GHG emissions of privately or outsourcing logistics activities. The fleet size of transportation has been determined as follows, by using the principle of Gencer et al. (2006); First, clustering around a given destination node within the network; Second, sizing the fleet:

Suppose that a destination Di is served by n origins Oj, and the origins are clustered in two areas which are separated by sea. The land area 2 comprises k origins plus a port 2, and the land area 1 comprises the destination Di, (n-k) origins plus a port 1. To move products in the area 2, a configuration of trucks 'truck2' with a capacity cap^{p}_{truck2}, an average of speed v2, and a rate of empty running $\varepsilon 2$ is used. While, in the area 1, a configuration of trucks 'truck1' with a capacity cap^{p}_{truck1}, an average speed v1, and a rate of empty running $\varepsilon 1$ is used.

Suppose that the FC projects to deliver a fraction β of the demand $d^p_{D_i}$ of product p from the area 2 via the port 2 & port 1, and the rest $1\text{-}\beta$ from the area 1. The relation (r*) provides the average number of trucks required to deliver products p from an origin belonging to area 2 to the port 2, and the average number of trucks required to deliver products p from the port 2 to the destination Di, both belonging to area 1.

Component 1 : Component 2 :

$$\underbrace{\sum_p \left[\frac{\beta}{k}\right] \cdot \frac{T_{Trip2}}{cap^p_{truck2} \cdot T_{eff}} \cdot d^p_{Di}}_{area2} \qquad \underbrace{\sum_p \left[\frac{\frac{\beta}{k} + (1\text{-}\beta)}{n}\right] \cdot \frac{T_{trip1}}{cap^p_{truck1} \cdot T_{eff}} d^p_{Di}}_{area1} \qquad (r^*)$$

All the parameters are defined in the section 2.3.2.1 of chapter 2 (constructive models of computing).

N.B. in the relation (r*, if $\beta = 0 \Rightarrow k = 0$, then the size of fleet transportation will be reduced to

$$\sum_p \left[\frac{1}{n}\right] \cdot \frac{T_{trip1}}{cap^p_{truck1} \cdot T_{eff}} d^p_{Di}$$

For example, in an optimal SC configuration Sj, the number of trucks required to move products from plants to the warehouse *w*, at period *t* is: $N^{fleet}_{jtw} = N^{area2}_{jtw} + N^{area1}_{jtw}$

$$N^{area2}_{jtw} = \sum_{p,b,m} prob_{tb} \cdot \left\{ \left[\frac{\beta}{k}\right] \cdot \frac{T_{Trip2}}{cap^p_{truck2} \cdot T_{eff}} \right\} \cdot q^{Sj}_{tbpmw}$$

&

$$N^{area1}_{jtw} = \sum_{p,b,m} prob_{tb} \cdot \left\{ \left[\frac{\frac{\beta}{k} + (1-\beta)}{n}\right] \cdot \frac{T_{trip1}}{cap^p_{truck1} \cdot T_{eff}} \right\} \cdot q^{Sj}_{tbpmw}$$

So, the variation of number of trucks between two consecutive periods t-1, and *t* is:

$$\Delta jw^t_{t-1} = N^{fleet}_{jtw} - N^{fleet}_{j(t-1)w} \qquad (r^*I)$$

***Concerning the GHG emissions per period *t* of the transport configuration, serving to move products to a given destination; the first-stage programming model should be asked to edit for each optimal Sj the term $Obj2_{jtD_i}^{Transport}$, for a given destination *Di*.

For example, GHG emissions generated by moving products from plants to the warehouse *w* is by the relation (*r**II) hereunder:

$$Obj2_{jtw}^{Transport} =$$

$$\sum_{b,w} prob_{tb}\left\{fe_{T_{tbw}}\right\}x_w^{Sj}$$

$$+\left\{\begin{array}{l}\sum_{b,p,m,w} prob_{tb}\left\{\begin{array}{l}weight_p\delta_{mw}\\ .ve_{T_{pmw}}\end{array}\right\}x_w^{Sj}q_{tbpmw}^{Sj}\\ +\sum_{b,p,m,w} prob_{tb}\left\{\begin{array}{l}weight_p\delta_{mw}\\ .(1-x_w^{Sj})e_{T_{pmw}}^{3PL}\end{array}\right\}q_{tbpmw}^{Sj}\end{array}\right\} \qquad (r^*II)$$

3.3.3. *The Stochastic Combinatory model*

For a horizon of multi-periods (indexed $t \in T$), the focal company FC desires selecting the best decarbonised SC configuration, which minimize a third objective function *OBJ3*.

OBJ3 is the total expected logistics cost incurred by the FC, after decarbonizing its SC before any LCR investment; and counteracting uncertain carbon policies by the implementation of a progressive plan of LCR investment, in freight transportation.

The best decarbonised SC configuration *S** corresponds to the Pareto solution Sj, which the minimized $OBJ3_{Sj}$ is the minimum:

$$Obj^{S^*} = \min\left[\min Obj3_{Sj}\right]; S_j \in \Gamma = \left\{S_1,...,S_j,...,S_{N_{Pareto}}\right\} \qquad \textbf{(40)}$$

This best SC design solution *S** leads not only to the optimal volume of LCR investment in transportation, but to the optimal level of 3PL integration within the SC as well.

- Decision variables:

The decision variables are binary;

$y^{l,1}_{tsm}$ & $y^{l,2}_{tsm}$: =1, if respectively LCR l1 (l2) approach l is introduced in freight transportation of supply s to plant m at period t.
=0, otherwise.

$y^{l,1}_{tw}$ & $y^{l,2}_{tw}$: =1, if respectively LCR l1 (l2) approach l is introduced in freight transportation of products to warehouse w at period t.
=0, otherwise.

$y^{l,1}_{tv}$ & $y^{l,2}_{tv}$: =1, if respectively LCR l1 (l2) is introduced in freight transportation of products to warehouse v at period t.
=0, otherwise.

$y^{l,1}_{tk}$ & $y^{l,2}_{tk}$: =1, if respectively LCR l1 (l2) is introduced in freight transportation of products to customer zone k at period t.
=0, otherwise.

$y^{l,1}_{tiw}$ & $y^{l,2}_{tiw}$: =1, if respectively LCR l1 (l2) is introduced in freight transportation of return of products, from distribution segment i to hybrid warehouse w at period t.
=0, otherwise.

$y^{l,1}_{tiu}$ & $y^{l,2}_{tiu}$: =1, if respectively LCR l1 (l2) is introduced in freight transportation of return of products, from distribution segment i to collection center u at period t.
=0, otherwise.

$y^{l,1}_{tm}$ & $y^{l,2}_{tm}$: =1, if respectively LCR l1 (l2) is introduced in freight transportation of recoverable products to plant m at period t.
=0, otherwise.

$y^{l,1}_{tz}$ & $y^{l,2}_{tz}$: =1, if respectively LCR l1 (l2) is introduced in freight transportation of unrecoverable products to disposal center z at period t.
=0, otherwise.

- Parameters:

** *Deterministic parameters:*

h	Average rate of inflation
$Cost_l$	Cost (in US. $) of individual LCR approach l at the present t=0
υ_l	Time (in years) to pay back the LCR approach l invested
$LCR_{l,1}$	Average Low Carbon Reduction rate investment l in land area 1 of the SC
$LCR_{l,2}$	Average Low Carbon Reduction rate investment l in land area 2 of the SC
ϑ	Factor of linearity for determining the result LCR rate of a group of LCR approaches
ξ	Factor defining the budget limitation of FC to invest in LCR approaches of freight transportation.

** *Stochastic parameters:*

$c^{CO2}_{0,b'}$	Started Internal carbon price for scenario b'
$\theta_{b'}$	Growth carbon price rate (in fraction), for scenario b'
$prob_{tb'}$	Probability of occurrence of scenario b', at period t

** *Stochastic parameters synthesised from the run of first-stage programming model*

$Obj2^{Transport}_{jtsm}$ & $Obj2^{Transport}_{j(t-1)sm}$	Total expected GHG emissions (in tons of CO2eq) to move supply s to plant m, in the optimal SC configuration Sj, respectively at period t, and period t-1.
$Obj2^{Transport}_{jtw}$ & $Obj2^{Transport}_{j(t-1)w}$	Total expected GHG emissions (in tons of CO2eq) to move products to warehouse w, in the optimal SC configuration Sj, respectively at period t, and period t-1.
$Obj2^{Transport}_{jtv}$ & $Obj2^{Transport}_{j(t-1)v}$	Total expected GHG emissions (in tons of CO2eq) to move products to warehouse v, in the optimal SC configuration Sj, respectively at period t, and period t-1.
$Obj2^{Transport}_{jtk}$ & $Obj2^{Transport}_{j(t-1)k}$	Total expected GHG emissions (in tons of CO2eq) to move products to customer zone k, in the optimal SC configuration Sj, respectively at period t, and period t-1.
$Obj2^{Transport}_{jtiw}$ & $Obj2^{Transport}_{j(t-1)iw}$	Total expected GHG emissions (in tons of CO2eq) to move returned products to hybrid warehouse w, in the optimal SC configuration Sj, respectively at period t, and period t-1.

$Obj2^{Transport}_{jtiu}$ & $Obj2^{Transport}_{j(t-1)iu}$ Total expected GHG emissions (in tons of CO2eq) to move returned products to collection center u, in the optimal SC configuration Sj, respectively at period t, and period t-1.

$Obj2^{Transport}_{jtm}$ & $Obj2^{Transport}_{j(t-1)m}$ Total expected GHG emissions (in tons of CO2eq) to move recoverable products to plant m, in the optimal SC configuration Sj, respectively at period t, and period t-1.

$Obj2^{Transport}_{jtz}$ & $Obj2^{Transport}_{j(t-1)z}$ Total expected GHG emissions (in tons of CO2eq) to move unrecoverable products to disposal center z, in the optimal SC configuration Sj, respectively at period t, and period t-1.

N^{area1}_{jtsm} & N^{area2}_{jtsm} Number of trucks required in respectively the area 1 (2) for moving supply s to plant m, at period t, and in Pareto optimal SC configuration Sj.

N^{area1}_{jtw} & N^{area2}_{jtw} Number of trucks required in respectively the area 1 (2) for moving products to warehouse w, at period t, and in Pareto optimal SC configuration Sj.

N^{area1}_{jtv} & N^{area2}_{jtv} Number of trucks required in respectively the area 1 (2) for moving products to warehouse v, at period t, and in Pareto optimal SC configuration Sj.

N^{area1}_{jtk} & N^{area2}_{jtk} Number of trucks required in respectively the area 1 (2) for moving products to customer zone k, at period t, and in Pareto optimal SC configuration Sj.

N^{area1}_{jtiw} & N^{area2}_{jtiw} Number of trucks required in respectively the area 1 (2) for moving returns from distribution segment i to hybrid warehouse v, at period t, and in Pareto optimal SC configuration Sj.

N^{area1}_{jtiu} & N^{area2}_{jtiu} Number of trucks required in respectively the area 1 (2) for moving returns from distribution segment i to collection center u, at period t, and in Pareto optimal SC configuration Sj.

N^{area1}_{jtm} & N^{area2}_{jtm} Number of trucks required in respectively the area 1 (2) for moving recoverable products to plant m, at period t, and in Pareto optimal SC configuration Sj.

N_{jtz}^{area1} & N_{jtz}^{area2}	Number of trucks required in respectively the area 1 (2) for moving unrecoverable products to disposal center z, at period t, and in Pareto optimal SC configuration Sj.
Δjsm_{t-1}^{t}	Variation of number of trucks required to move supply s from corresponding suppliers to plant m between two consecutive periods t-1 and t, in the optimal SC configuration Sj
Δjw_{t-1}^{t}	Variation of number of trucks required to move products from plants to warehouse w between two consecutive periods t-1 and t, in the optimal SC configuration Sj
Δjv_{t-1}^{t}	Variation of number of trucks required to move products from plants to warehouse v between two consecutive periods t-1 and t, in the optimal SC configuration Sj
Δjk_{t-1}^{t}	Variation of number of trucks required to move products from warehouses to customer zone k between two consecutive periods t-1 and t, in the optimal SC configuration Sj
Δjiw_{t-1}^{t}	Variation of number of trucks required to move returns from distribution segment i to hybrid warehouse w between two consecutive periods t-1 and t, in the optimal SC configuration Sj
Δjiu_{t-1}^{t}	Variation of number of trucks required to move returns from distribution segment i to collection centers u between two consecutive periods t-1 and t, in the optimal SC configuration Sj
Δjm_{t-1}^{t}	Variation of number of trucks required to move recoverable products to plant m between two consecutive periods t-1 and t, in the optimal SC configuration Sj
Δjz_{t-1}^{t}	Variation of number of trucks required to move unrecoverable products to disposal center z between two consecutive periods t-1 and t, in the optimal SC configuration Sj

- Objective function:

OBJ3: minimize $Obj3_{Sj}$

X_{Sj} is expressed in the equation (27), and corresponds, for each Pareto solution

$S_j \in \Gamma = \left\{ S_1, \ldots, S_j, \ldots, S_{N_{Pareto}} \right\}$, to total cost = **A**+ **B** + **C** - **D**, where:

A: Total logistics cost of the optimal configuration Sj, which is provided by running the first-stage programming model

B: Total cost of carbon of the decarbonized SC, before any investment in LCR approaches. It is equal to the average internal carbon price of the multi-period horizon multiplied by Total expected GHG emissions of the optimal configuration Sj,

C: Total cost of potential investment in LCR approaches, and

D: Savings of the potential LCR investment implemented within different fleet configurations of the SC.

The table **3.3** shows the analytical expression of the objective function OBJ3, to minimize under three types of constraints:

- Carbon abatement (28) to (36);
- Budget limitation expressed in terms of total expected logistics costs (37);
- Investment priority (38-45), where the preference order of investment for the FC is supposed as:

1) Aerodynamics; 2) Low rolling resistance; 3) Driver training; 4) Transmission efficiency; 5) Engine efficiency, and 6) Hybridization.

- The binary constraints of the decisions variables (46)

Carbon Abatement:

The LCR investment at period t will occurs, if the variation of carbon cost between t-1, and t is greater than the LRC costs divided by their payback durations, corresponding to probable increase of transportation fleet between t-1, and t.

We suppose that the individual LCR technologies introduced in MDV & HDV have approximatively the same cost, but may have different LCR rate (see table **3.1**)

$$\sum_{b'} c_{0,b'}^{CO_2}.\theta_{b'}^{(t-1)}\left\{\begin{matrix}\theta_{b'}.prob_{tb'}.Obj2_{jtsm}^{Transport}\\ -prob_{(t-1)b'}.Obj2_{j(t-1)sm}^{Transport}\end{matrix}\right\}\geq \vartheta.\sum_{l}(1+h)^{t}.\frac{Cost_l}{\upsilon_l}.(y_{jtsm}^{l,1}+y_{jtsm}^{l,2}).\Delta jsm_{t-1}^{t};\forall j,t,s,m \tag{28}$$

$$\sum_{b'} c_{0,b'}^{CO_2}.\theta_{b'}^{(t-1)}.\left\{\begin{matrix}\theta_{b'}.prob_{tb'}.Obj2_{jtw}^{Transport}\\ -prob_{(t-1)b'}.Obj2_{j(t-1)w}^{Transport}\end{matrix}\right\}\geq \vartheta.\left(\sum_{l}(1+h)^{t}.\frac{Cost_l}{\upsilon_l}.(y_{jtw}^{l,1}+y_{jtw}^{l,2}).\Delta jw_{t-1}^{t}\right);\forall j,t,w \tag{29}$$

$$\sum_{b'} c_{0,b'}^{CO_2}.\theta_{b'}^{(t-1)}.\left\{\begin{matrix}\theta_{b'}.prob_{tb'}.Obj2_{jtv}^{Transport}\\ -prob_{(t-1)b'}.Obj2_{j(t-1)v}^{Transport}\end{matrix}\right\}\geq \vartheta.\left(\sum_{l}(1+h)^{t}.\frac{Cost_l}{\upsilon_l}.(y_{jtv}^{l,1}+y_{jtv}^{l,2}).\Delta jv_{t-1}^{t}\right);\forall j,t,v \tag{31}$$

$$\sum_{b'} c_{0,b'}^{CO_2}.\theta_{b'}^{(t-1)}.\left\{\begin{matrix}\theta_{b'}.prob_{tb'}.Obj2_{jtk}^{Transport}\\ -prob_{(t-1)b'}.Obj2_{j(t-1)k}^{Transport}\end{matrix}\right\}\geq \vartheta.\left(\sum_{l}(1+h)^{t}.\frac{Cost_l}{\upsilon_l}.(y_{jtk}^{l,1}+y_{jtk}^{l,2}).\Delta jk_{t-1}^{t}\right);\forall j,t,k \tag{32}$$

$$\sum_{b'} c_{0,b'}^{CO_2}.\theta_{b'}^{(t-1)}\left\{\begin{matrix}\theta_{b'}.prob_{tb'}.Obj2_{jtiw}^{Transport}\\ -prob_{(t-1)b'}.Obj2_{j(t-1)iw}^{Transport}\end{matrix}\right\}\geq \vartheta.\left(\sum_{l}(1+h)^{t}.\frac{Cost_l}{\upsilon_l}.(y_{jtiw}^{l,1}+y_{jtiw}^{l,2}).\Delta jiw_{t-1}^{t}\right);\forall j,t,i,w \tag{33}$$

$$\sum_{b'} c_{0,b'}^{CO_2}.\theta_{b'}^{(t-1)}.\left\{\begin{matrix}\theta_{b'}.prob_{tb'}.Obj2_{jtiu}^{Transport}\\ -prob_{(t-1)b'}.Obj2_{j(t-1)iu}^{Transport}\end{matrix}\right\}\geq \vartheta.\left(\sum_{l}(1+h)^{t}.\frac{Cost_l}{\upsilon_l}.(y_{jtiu}^{l,1}+y_{jtiu}^{l,2}).\Delta jiu_{t-1}^{t}\right);\forall j,t,i,u \tag{34}$$

$$\sum_{b'} c_{0,b'}^{CO_2}.\theta_{b'}^{(t-1)}.\left\{\begin{matrix}\theta_{b'}.prob_{tb'}.Obj2_{jtm}^{Transport}\\ -prob_{(t-1)b'}.Obj2_{j(t-1)m}^{Transport}\end{matrix}\right\}\geq \vartheta.\left(\sum_{l}(1+h)^{t}.\frac{Cost_l}{\upsilon_l}.(y_{jtm}^{l,1}+y_{jtm}^{l,2}).\Delta jm_{t-1}^{t}\right);\forall j,t,m \tag{35}$$

$$\sum_{b'} c_{0,b'}^{CO_2}.\theta_{b'}^{(t-1)}.\left\{\begin{matrix}\theta_{b'}.prob_{tb'}.Obj2_{jtz}^{Transport}\\ -prob_{(t-1)b'}.Obj2_{j(t-1)z}^{Transport}\end{matrix}\right\}\geq \vartheta.\left(\sum_{l}(1+h)^{t}.\frac{Cost_l}{\upsilon_l}.(y_{jtz}^{l,1}+y_{jtz}^{l,2}).\Delta jz_{t-1}^{t}\right);\forall j,t,z \tag{36}$$

Binary constraint:

$$y_{jtsm}^{l,1};y_{jtsm}^{l,2};y_{jtw}^{l,1};y_{jtw}^{l,2};y_{jtv}^{l,1};y_{jtv}^{l,2};y_{jtk}^{l,1};y_{jtk}^{l,2};$$
$$y_{jtiw}^{l,1};y_{jtiw}^{l,2};y_{jtiu}^{l,1};y_{jtiu}^{l,2};y_{jtm}^{l,1};y_{jtm}^{l,2};y_{jtz}^{l,1};y_{jtz}^{l,2}\in\{0,1\} \quad (46)$$
$$\forall j,l,t,s,m,w,v,i,u,z$$

Investment Priority constraint:

$$\left\{y_{jtsm}^{4,1}\geq y_{jtsm}^{5,1}\geq y_{jtsm}^{6,1}\geq y_{jtsm}^{2,1}\geq y_{jtsm}^{1,1}\geq y_{jtsm}^{3,1}\right\}\ \&\ \left\{y_{jtsm}^{4,2}\geq y_{jtsm}^{5,2}\geq y_{jtsm}^{6,2}\geq y_{jtsm}^{2,2}\geq y_{jtsm}^{1,2}\geq y_{jtsm}^{3,2}\right\}; \quad (38)$$

$$\left\{y_{jtw}^{4,1}\geq y_{jtw}^{5,1}\geq y_{jtw}^{6,1}\geq y_{jtw}^{2,1}\geq y_{jtw}^{1,1}\geq y_{jtw}^{3,1}\right\}\ \&\ \left\{y_{jtw}^{4,2}\geq y_{jtw}^{5,2}\geq y_{jtw}^{6,2}\geq y_{jtw}^{2,2}\geq y_{jtw}^{1,2}\geq y_{jtw}^{3,2}\right\}; \quad (39)$$

$$\left\{y_{jtv}^{4,1}\geq y_{jtv}^{5,1}\geq y_{jtv}^{6,1}\geq y_{jtv}^{2,1}\geq y_{jtv}^{1,1}\geq y_{jtv}^{3,1}\right\}\ \&\ \left\{y_{jtv}^{4,2}\geq y_{jtv}^{5,2}\geq y_{jtv}^{6,2}\geq y_{jtv}^{2,2}\geq y_{jtv}^{1,2}\geq y_{jtv}^{3,2}\right\}; \quad (40)$$

$$\left\{y_{jtk}^{4,1}\geq y_{jtk}^{5,1}\geq y_{jtk}^{6,1}\geq y_{jtk}^{2,1}\geq y_{jtk}^{1,1}\geq y_{jtk}^{3,1}\right\}\ \&\ \left\{y_{jtk}^{4,2}\geq y_{jtk}^{5,2}\geq y_{jtk}^{6,2}\geq y_{jtk}^{2,2}\geq y_{jtk}^{1,2}\geq y_{jtk}^{3,2}\right\}; \quad (41)$$

$$\left\{y_{jtiw}^{4,1}\geq y_{jtiw}^{5,1}\geq y_{jtiw}^{6,1}\geq y_{jtiw}^{2,1}\geq y_{jtiw}^{1,1}\geq y_{jtiw}^{3,1}\right\}\ \&\ \left\{y_{jtiw}^{4,2}\geq y_{jtiw}^{5,2}\geq y_{jtiw}^{6,2}\geq y_{jtiw}^{2,2}\geq y_{jtiw}^{1,2}\geq y_{jtiw}^{3,2}\right\}; \quad (42)$$

$$\left\{y_{jtiu}^{4,1}\geq y_{jtiu}^{5,1}\geq y_{jtiu}^{6,1}\geq y_{jtiu}^{2,1}\geq y_{jtiu}^{1,1}\geq y_{jtiu}^{3,1}\right\}\ \&\ \left\{y_{jtiu}^{4,2}\geq y_{jtiu}^{5,2}\geq y_{jtiu}^{6,2}\geq y_{jtiu}^{2,2}\geq y_{jtiu}^{1,2}\geq y_{jtiu}^{3,2}\right\}; \quad (43)$$

$$\left\{y_{jtm}^{4,1}\geq y_{jtm}^{5,1}\geq y_{jtm}^{6,1}\geq y_{jtm}^{2,1}\geq y_{jtm}^{1,1}\geq y_{jtm}^{3,1}\right\}\ \&\ \left\{y_{jtm}^{4,2}\geq y_{jtm}^{5,2}\geq y_{jtm}^{6,2}\geq y_{jtm}^{2,2}\geq y_{jtm}^{1,2}\geq y_{jtm}^{3,2}\right\}; \quad (44)$$

$$\left\{y_{jtz}^{4,1}\geq y_{jtz}^{5,1}\geq y_{jtz}^{6,1}\geq y_{jtz}^{2,1}\geq y_{jtz}^{1,1}\geq y_{jtz}^{3,1}\right\}\ \&\ \left\{y_{jtz}^{4,2}\geq y_{jtz}^{5,2}\geq y_{jtz}^{6,2}\geq y_{jtz}^{2,2}\geq y_{jtz}^{1,2}\geq y_{jtz}^{3,2}\right\}. \quad (45)$$

$$\forall j,s,m,w,v,i,u,z$$

Budget limitation:

Depending on its carbon reporting quality to attract investors, and its degree of proactivity to build a climate resilient SC, the FC defines a factor ξ to express the budget limitation in LCR approaches investment.

$$
\xi_{budget}\cdot\left\{\begin{array}{l}
\sum\limits_{s,m} Obj1^{Transport}_{jtsm}+\sum\limits_{w} Obj1^{Transport}_{jtw}\\
+\sum\limits_{v} Obj1^{Transport}_{jtv}+\sum\limits_{k} Obj1^{Transport}_{jtk}\\
+\sum\limits_{i,w} Obj1^{Transport}_{jtiw}+\sum\limits_{i,u} Obj1^{Transport}_{jtiu}\\
+\sum\limits_{m} Obj1^{Transport}_{jtm}+\sum\limits_{z} Obj1^{Transport}_{jtz}
\end{array}\right\}\geq \vartheta.(1+h)^{t}\left\{\begin{array}{l}
\sum\limits_{l,s,m} Cost_{l}.\left\{\begin{array}{l} y^{l,1}_{jtsm}(N^{area1}_{jtsm}-N^{area1}_{j(t-1)sm})\\ +y^{l,2}_{jtsm}.(N^{area2}_{jtsm}-N^{area2}_{j(t-1)sm})\end{array}\right\}\\
+\sum\limits_{l,w} Cost_{l}.\left\{\begin{array}{l} y^{l,1}_{jtw}(N^{area1}_{jtw}-N^{area1}_{j(t-1)w})\\ +y^{l,2}_{jtw}.(N^{area1}_{jtw}-N^{area1}_{j(t-1)w})\end{array}\right\}\\
+\sum\limits_{l,v} Cost_{l}.\left\{\begin{array}{l} y^{l,1}_{jtv}(N^{area1}_{jtv}-N^{area1}_{j(t-1)v})\\ +y^{l,2}_{jtv}(N^{area1}_{jtv}-N^{area1}_{j(t-1)v})\end{array}\right\}\\
+\sum\limits_{l,k} Cost_{l}.\left\{\begin{array}{l} y^{l,1}_{jtk}(N^{area1}_{jtk}-N^{area1}_{j(t-1)k})\\ +y^{l,2}_{jtk}(N^{area1}_{jtk}-N^{area1}_{j(t-1)k})\end{array}\right\}\\
+\sum\limits_{l,i,k} Cost_{l}.\left\{\begin{array}{l} y^{l,1}_{jtiw}(N^{area1}_{jtiw}-N^{area1}_{j(t-1)iw})\\ +y^{l,2}_{jtiw}(N^{area1}_{jtiw}-N^{area1}_{j(t-1)iw})\end{array}\right\}\\
+\sum\limits_{l,i,u} Cost_{l}.\left\{\begin{array}{l} y^{l,1}_{jtiu}(N^{area1}_{jtiu}-N^{area1}_{j(t-1)iu})\\ +y^{l,2}_{jtiu}(N^{area1}_{jtiu}-N^{area1}_{j(t-1)iu})\end{array}\right\}\\
+\sum\limits_{l,m} Cost_{l}.\left\{\begin{array}{l} y^{l,1}_{jtm}(N^{area1}_{jtm}-N^{area1}_{j(t-1)m})\\ +y^{l,2}_{jtm}(N^{area1}_{jtm}-N^{area1}_{j(t-1)m})\end{array}\right\}\\
+\sum\limits_{l,z} Cost_{l}.\left\{\begin{array}{l} y^{l,1}_{jtz}(N^{area1}_{jtz}-N^{area1}_{j(t-1)z})\\ +y^{l,2}_{jtz}(N^{area1}_{jtz}-N^{area1}_{j(t-1)z})\end{array}\right\}
\end{array}\right\} \quad (37)
$$

Table 3.3

The objective function of the second-stage stochastic modelling approach

$$
\begin{aligned}
&\underbrace{Obj_1^{S_j}}_{A} \\
&\underbrace{+\, Obj_2^{S_j} . \sum_{t,b'} c_{0,b'}^{CO_2} . \theta_{b'}^{t} . prob_{tb'}}_{B} \\
&\underbrace{\begin{aligned}
&\sum_{l,t,s,m} (1+h)^t . Cost_l . (y_{jtsm}^{l,1} + y_{jtsm}^{l,2}) . \Delta_{jsm(t-1)}^{t} + \sum_{l,t,w} (1+h)^t . Cost_l . (y_{jtw}^{l,1} + y_{jtw}^{l,2}) . \Delta_{jw(t-1)}^{t} \\
&+ \sum_{l,t,v} (1+h)^t . Cost_l . (y_{jtv}^{l,1} + y_{jtv}^{l,2}) . \Delta_{jv(t-1)}^{t} + \sum_{l,t,k} (1+h)^t . Cost_l . (y_{jtk}^{l,1} + y_{jtk}^{l,2}) . \Delta_{jk(t-1)}^{t} \\
&+ \sum_{l,t,i,w} (1+h)^t . Cost_l . (y_{jtiw}^{l,1} + y_{jtiw}^{l,2}) . \Delta_{jiw(t-1)}^{t} + \sum_{l,t,i,u} (1+h)^t . Cost_l . (y_{jtiu}^{l,1} + y_{jtiu}^{l,2}) . \Delta_{jiu(t-1)}^{t} \\
&+ \sum_{l,t,m} (1+h)^t . Cost_l . (y_{jtm}^{l,1} + y_{jtm}^{l,2}) . \Delta_{jm(t-1)}^{t} + \sum_{l,t,z} (1+h)^t . Cost_l . (y_{jtz}^{l,1} + y_{jtz}^{l,2}) . \Delta_{jz(t-1)}^{t}
\end{aligned}}_{C} \qquad (27) \\
&\underbrace{- \vartheta . \sum_{t,b'} prob_{t,b'} . c_{0,b'}^{CO_2} . \left\{ \begin{aligned}
&\sum_{s,m,l} (LCR_{l,1} \cdot y_{jtsm}^{l,1} + LCR_{l,2} \cdot y_{jtsm}^{l,2}) . Obj2_{jtsm} \\
&+ \sum_{w,l} (LCR_{l,1} \cdot y_{jtw}^{l,1} + LCR_{l,2} \cdot y_{jtw}^{l,2}) . Obj2_{jtw} \\
&+ \sum_{v,l} (LCR_{l,1} \cdot y_{jtv}^{l,1} + LCR_{l,2} \cdot y_{jtv}^{l,2}) . Obj2_{jtv} \\
&+ \sum_{k,l} (LCR_{l,1} \cdot y_{jtk}^{l,1} + LCR_{l,2} \cdot y_{jtk}^{l,2}) . Obj2_{jtk} \\
&+ \sum_{i,w,l} (LCR_{l,1} \cdot y_{jtiw}^{l,1} + LCR_{l,2} \cdot y_{jtiw}^{l,2}) . Obj2_{jtiw} \\
&+ \sum_{i,u,l} (LCR_{l,1} \cdot y_{jtiu}^{l,1} + LCR_{l,2} \cdot y_{jtiu}^{l,2}) . Obj2_{jtiu} \\
&+ \sum_{m,l} (LCR_{l,1} \cdot y_{jtm}^{l,1} + LCR_{l,2} \cdot y_{jtm}^{l,2}) . Obj2_{jtm} \\
&+ \sum_{z,l} (LCR_{l,1} \cdot y_{jtz}^{l,1} + LCR_{l,2} \cdot y_{jtz}^{l,2}) . Obj2_{jtz}
\end{aligned} \right\}}_{D}
\end{aligned}
$$

3.3.4. Discussion

In this section, we discuss some interesting managerial insights, which can be deducted from the implementation of the two models.

we refer to the working case study of a medium enterprise FC, which manufactures, distributes, and recover three categories of microwave ovens.

In a horizon of time of 6 years, and in the context of business environment uncertainties, the main objectives of the Focal Company are:

1) responding to 1/6 of the North American market in terms of micro-wave ovens, and exporting a portion of its production to European market,

2) integrating the logistics outsourcing decision in its SC design, to build a climate resilient SC

3) Optimizing its investment in Low Carbon Reduction of freight transportation to counteract the uncertain carbon policies

Concerning the implementation of First-stage stochastic modelling: More details are in Ameknassi *et al.* (2016).

Concerning the implementation of Second- stage model:

- the code of second-stochastic model, is written in IBM ILOG CPLEX Studio 6.1., and the data of carbon price stochastic plan, LCR approaches, and the synthesized data (e.g. section 4.2), are reported in an Excel Microsoft file, and are declared in IBM ILOG CPLEX Studio 6.1.
- By introducing the data of each Sj in the second stage programming model, **9 576** decision variables must be identified, with the minimized OBJ3j
- The minimum of the minimum OBJ3j corresponds to the best climate resilient SC configuration. It indicates the optimal integration of 3PL within the SC, and the optimal progressive investment in LCR freight transportation approaches to counteract the uncertain carbon policies, in the context of business uncertainty, and within a multi-period horizon of 6 years.

As mentioned in the introduction, Huang *et al.* (2009) have reported that more than 75% of the Green House Gases (GHG) emissions of many industry sectors come from their SCs. In Brown (2009), and according to the World Economic, 15% of GHG emissions come from forward logistics activities, and about 5% from reverse logistics. The forum suggests thirteen effective strategies to decarbonize the SCs, and among the most effective ones: Improving the network logistics planning, through 1) global SC optimization, and 2) LCR approaches investment, notably in the freight transportation technologies. According to the forum, 24% of carbon reduction may be realized by the first strategy, and according to Meszler *et al.* (2015), for tractor with 3 trailers, low Carbon efficiency technology package could result in LCR of about 48-56%, and cost increase of about 15-25%, with a payback in 1 – 3 years, depending on the discount rate, and the diesel price. So, 24 % *20 % + (100-24) %*20%*((48+56)/2) % = 12.5%

represent the 63.5% of potential carbon reduction that may be realized, by optimizing the global SC, and investing in LCR freight transport technologies.

However, as the logistics are supposed not to be the core activities of the FC, logistics outsourcing may be an effective strategy to an optimum level of extent (Das *et al.* 2006). Regardless the optimality or not of the common outsourcing transportation level of 70% (Langley & Gemini, 2013), and without considering carbon cost imposition, the 3PLs may reduce the logistics costs by an average of 15%, but they could involve a risk of increasing the GHG emissions by 25% (Blanco & Craig, 2009; CDP, 2016). So, the main objectives are: 1) to optimize the level of logistics outsourcing for balancing the total cost and total GHG emissions of the climate resilient SC; 2) to determine how this level is dispatched within the echelons of the SC; 3) to identify how the LCR of freight transportation must be invested inside the different truck configurations of the SC; and 4) to help future selected 3PLs partners to manage the climate change risks.

3.4. Conclusion

This work proposes a two-stage stochastic modelling approach to integrate logistics outsourcing decision in climate change resilient SC design problems. As part of Paris negotiations, 187 countries submitted Post-2020 Intended Nationally Determined Contributions (INDCs) to the United Nations Framework Convention of Climate Change (UNFCCC). These climate commitments mean more legal requirements of businesses, and more climate actions are needed to support the climate change resilience of focal companies (FCs) and their suppliers within the SCs. According to the last report of Carbon Disclosure Project CDP report, the awareness and actions of suppliers vis-à-vis the climate risks remain insufficient to build resilient SCs, and FCs should help their suppliers to manage effectively their climate risks. We consider the 3PLs as potential important partners of a FC to effectively circulate the sustainable practices within its global SC, and the integration of logistics outsourcing decisions in the design of sustainable SC problem is of strategic importance. The first stage of stochastic modelling approach has been presented in our recent work submitted to the International Journal of Production Economics, and consists of suggesting a Stochastic, Multi-Objective, Multi-Period, and Multi-Product programming model, integrating logistics outsourcing decisions in a closed-loop SC design, before any investment in emerging Low Carbon Reduction (LCR) Technologies. The result has been a set of Pareto optimal SC configurations, which identify the logistics activities to be outsourced from those to be performed in-house. A multi-criteria analysis would be suggested to select the best SC configuration, however, we suggest a second-stage stochastic model, as a normative decision, not only to select the best SC configuration, but to determine the optimal progressive LCR investment in freight transportation, for counteracting the uncertain future carbon policies, as well. To do so, we; 1) Synthesized the evolution of heterogeneous transportation fleet size of each Pareto solution of the 1^{st} stage model; 2) Established a Carbon stochastic price plan in the context of voluntary disclosure Carbon regime; 3) Proposed a Stochastic, Mono-Objective, and Multi-Period Combinatory programming model, to minimize the total logistics cost, after incurring carbon cost, and investing in Low Carbon Reduction of freight transportation. The model is subject to carbon abatement constraint, and Low Carbon reduction approaches' prioritization. Running the 2^{d} stage Combinatory model leads to identify optimal levels of 3PL integration, and Low Carbon investment.

This work presents some limitations, that it is worth to deal with in further researches. The second-stage stochastic model consider only the LCR technologies in freight transportation, but should be extended to other energy efficiencies related to bio-fuel utilization, and related to warehousing & material handling. The stochastic plan of carbon price establishment, in the context of voluntary carbon disclosure regime, remain open to a lot of improvements, because the volatile nature of carbon prices. The operational management of empty back hauls may lead to develop more effective transportation itineraries, and more effective transportation schedules. So, the evolution of fleet size may be subject to serious modifications, which affect the optimality of the second-stage model. Finally, the second-stage stochastic modelling approach should be completed by a supplier robust selection approach to build sustainable SCs.

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Chapter 4:

Third Party Logistics Providers Selection in the Context of Sustainable Supply Chains:

A Robust Integrated Approach

Highlights:

- The logistics activities being outsourced are modelled as a sustainable business process;
- Criteria, risks, and two quality engineering functions are defined to optimize the process;
- QFD-Fuzzy AHP is used to parametrize the factors influencing the 3PL selection;
- Taguchi Robust Design is used to optimize the settings of selection criteria;
- DEA is used to shorten the list of candidates, to be compared to the optimum of Taguchi.

Résumé

Ce chapitre développe une approche intégrée robuste pour sélectionner un prestataire logistique « Third-Party Logistics (3PL) », dans le cadre des chaînes logistiques durables. Elle ne considère que les activités logistiques à externaliser comme un processus d'affaires qui transforme les inputs « critères de Ressources et Capabilités » en outputs « critères de Capacités & Performances », pendant qu'il est soumis à des perturbations « Risques d'Affaires ». Deux fonctions de transfert ont été considérées pour représenter la valeur ajoutée du processus : Efficacité et Robustesse. Tout d'abord, l'Analyse d'Enveloppement des Données (DEA) est effectuée pour limiter la liste des candidats 3PL, seulement à ceux d'efficience relative comparable. Deuxièmement, l'outil intégré QFD-Fuzzy AHP est effectuée pour paramétrer les facteurs influant sur le processus de sélection des 3PLs. Troisièmement, La technique de Conception Robuste est effectuée pour trouver l'optimum de Taguchi; un 3PL "virtuel", dont les critères de sélection sont optimisés. Enfin, les candidats 3PL seront comparés à l'optimum, et le lauréat doit être le plus proche de cet optimum. Ainsi, les coûts supplémentaires des ressources et des capacités pas nécessairement utilisées seraient évités, et le processus externalisé serait quasiment le plus efficient et le plus résilient aux perturbations. Un exemple illustratif de la sélection d'un 3PL pour la logistique inverse est fourni pour démontrer l'applicabilité de l'approche proposée, et pour mettre en évidence les faiblesses des approches de sélection les plus populaires.

Abstract

This chapter develops a robust integrated approach to select a Third-Party Logistics provider (3PL), in the context of sustainable Supply Chains (Scs). It considers logistics activities being outsourced as a business process transforming inputs "resources & capabilities" into outputs "Capacity & performances", while is being submitted to disruptions "Business risks". Two transfer functions: Efficiency & Robustness, are considered to represent the value added of the process. First, DEA method is performed to shorten the list of 3PL candidates, to only those of comparative relative efficiencies. Second, multi-stage QFD-Fuzzy AHP is performed to parametrize the factors influencing the process of 3PL selection. Third, Robust Design Technique is performed to find the Taguchi optimum; a "virtual" 3PL, in which the settings of selection factors are optimized. Finally, the 3PL candidates will be compared to the optimum, and the winner should be the closest one to this optimum. Doing so, the incremental costs of idle resources and capabilities will be avoided, and the process being outsourced is nearly the most efficient and the most resilient. An illustrative example of 3PL selection for reverse logistics is provided to demonstrate the applicability of the suggested approach, and to show the weaknesses of the most popular selection approaches.

Keywords:

- Sustainable Supply Chains;
- Third Party logistics providers;
- Data Envelopment Analysis;
- Fuzzy AHP/Quality Function Deployment;
- Taguchi Robust Design.

4.1. Introduction

In "Sustainable" SCs, environmental and social criteria need to be fulfilled by the members to remain within the SCs, while it is expected that competitiveness would be maintained through meeting customer needs, and related economic criteria (Seuring & Müller, 2008). Nowadays, more than 8 000 businesses around the world have signed the United Nation Global Compact pledging to show good global citizenship in the areas of human rights, labor standards and environmental protection (Wharton, 2012). Media & Non-Governmental Organizations (ONG) continue to put more pressure on public & private organizations to control their outsourcing practices, while considering all the aspects of sustainability in their call for tenders (Sullivan & Ngwenyama, 2005).

Outsourcing is a flexible strategy, which involves allocating or reallocating business activities from an internal source to an external source (Schniederjans *et al.* 2015). It is currently one of the hottest topics in business practices; in particular in the field of logistics. Currently, about 40% of the global logistics activities (e.g. Inbound, outbound, and reverse logistics) are outsourced to 3PLs (Langley & Capgemini, 2015). According to the recent study of Langley & Capgemini (2013), Total of logistics expenditure represents 12 to15% of the sale revenue of industrial organizations, and logistics outsourcing can reduce the logistics cost by 15%, the inventory cost by 8%, and the logistics fixed-asset by 26%. Logistics service provider (3PL) as a supplier of services, has a potential role to act as a mediator between interfaces of a Sustainable SC. It may help a company to facilitate the implementation of sustainable practices in both upstream and downstream of the SC (Lieb & Lieb, 2010). However, according to Evangelista *et al.* (2011); Wolf & Seuring (2010), and Blanco & Craig (2009), 3PL seem not undertake concrete sustainable initiatives vis-à-vis the energy efficiency, the Green House Gas emissions, the traffic congestion, and the working conditions. Their role seems rather to be concentrated on the deployment of conventional competitiveness criteria such as cost, quality, and flexibility. Whence the risk involved by the logistics outsourcing strategy to miss the sustainable development commitments. In Langley & Capgemini (2014), every year about 30% of 3PL' users decide systematically to return to in-source some or all of their logistics needs, despite would this can result in terms of loss of time, effort and money.

In supply chain design, and logistics literature, logistics outsourcing decisions have been investigated by asking the key questions; Why? What? Where? Who? How? & To what extent? (Hätönen & Eriksson, 2009). The reader may consult these papers, for more details around the subject:

- "Why?" outsourcing logistics (Anderson *et al*. 2011; Hsiao *et al*. 2010; Jayaram & Tan, 2010);
- "What?" logistics activities should be outsourced (Serrato *et al.* 2007; Savaskan *et al.* 2004);
- "Where?" outsourcing logistics (Bunyaratavej *et al.* 2007; Graf & Mudambi, 2005);
- "Who?" is the most *effective* 3PL to select for performing a logistics activity (Ho *et al.* 2012; Hamdan & Rogers, 2008);
- "How?" to manage the relationship between outsourcing companies and 3PLs (Yang & Zhao, 2016; Flynn *et al.* 2010); and
- "To what extent?" 3PL may be integrated to optimize the green SC configuration (Ameknassi *et al.* 2016)

In this work, we suppose that the Focal Company FC has designed its green SC, and determined the optimal configuration of the SC which strategically, and financially distinguishes the logistics activities to outsource, from those to perform in house (Ameknassi *et al.* 2016). We focus on the question of "Who?" is the most *efficient* 3PL to select in the context of a sustainable SC.

Developing a sound 3PL selection decision making, in the context of sustainable SCs depends on the ability to identify and parametrize the most relevant factors, that influence the sustainability of the logistics process being outsourced. It depends also on the ability to evaluate the process efficiency, which is subjected to inherent disturbances affecting the process within the SC. We shall investigate in this paper the 3PL selection criteria, and the popular selection methods used to deal with the supplier selection problem, and identify the impediments applying them in the context of sustainable SCs. Then we suggest a Robust Integrated Approach: The ''DEA-QDF/fuzzy Analytic Hierarchic Process AHP-Taguchi Robust Design''. This approach is intended to be:

- Relevant, by appropriately identifying, categorizing, and calibrating the sustainable selection criteria;
- Consistent, by ensuring the coherence of criteria with the real logistics needs, and the business strategies of the outsourcing company; and

- Robust by capturing the uncertainties related to the uncontrollable risk factors influencing the efficiency of the logistics process being outsourced.

An example of 3PL selection problem for reverse logistics is introduced to construct the integrated approach, by showing the pros and the cons of the most popular selection methods.

To the knowledge of the authors, it is the first time the orthogonal Taguchi Robust Design plan is transferred from engineering process robust optimization to 3PL selection problem, to consider the resource limitations and capture the business uncertainties, which are generally neglected by the previous researches in the field.

The remainder of this chapter is organized as follows. After a brief overview of the 3PL selection problem in the section 4.2, we define in the section 4.3 the methodology to deal with the selection of 3PL in the context of Sustainable SCs. From the literature, we suggest the sets of business strategies, and generic logistics requirements of different logistics processes within a sustainable SC. We suggest, categorize, and calibrate the main factors influencing the efficiency and the robustness of the logistics process being outsourced. Then, we present in three phase the procedure for selecting a sustainable 3PL. In the section 4.4, we demonstrate the applicability of the robust integrated approach by performing an illustrative example of 3PL selection problem for reverse logistics. We provide the analytical models of DEA, QFD-based methods, and Taguchi robust design technique, and show progressively their pros and cons, and we discuss some interesting managerial insights concerning the 3PL selection problem. Finally, in the section 4.5 we draw the conclusion.

4.2. Problem of 3PL Selection

Third-Party logistics (3PL), is a company that works with shippers on a contract basis, to manage their logistics operations. According to Bask (2001), it may offer three distinguished services:

- Routine services which include all types of basic transportation and warehousing;
- Standard services which contain some easy customized operations like special transportation where products need to be cooled, heated or moved in tanker trucks; and
- Customized services which consist of different postponement services like light assembly of product, packing product and/or recovery, and reverse logistics operations.

Sink & Langley (1997) had provided a conceptual model of the 3PL outsourcing process with five stages: 1) Identify the need to outsource logistics; 2) develop feasible alternatives; 3) evaluate and select the 3PL supplier; 4) implement service; and 5) ongoing service assessment. The 3PL selection is a multi-criteria problem, in which most of the selection criteria are conflictual. Recent works of 3PL selection have suggested many selection criteria, and have adopted a variety of evaluation methods, that may be summarized in the following subsections:

4.2.1 Selection Criteria

In the logistics literature, the number of proposed selection criteria for a decision making varied between 4 and 31, with an average number of 9 criteria (Wittstruck & Teuteberg, 2011), and the logistics activities being outsourced might be the general logistics or the reverse logistics;

Two examples of general logistics outsourcing are: Jayaram & Tan, (2010) suggested 6 criteria: 1) Scope of resources; 2) Industry knowledge; 3) Commitment to quality; 4) Ability to meet delivery due dates; 5) Financial stability and staying power; and 6) Ability to respond to unexpected demand. In a recent empirical study, Coltman *et al.* (2011) proposed 10 criteria: 1) Reliable performance; 2) Delivery speed; 3) Professionalism; 4) Service handling and support, 5) Supply chain flexibility; 6) Track and trace; 7) Service recovery; 8) Supply chain capacity; 9) Proactive innovation, and 10) Parity price.

Two other examples of reverse logistics outsourcing are: Meade & Sarkis (2002) had suggested 4 criteria: 1) Location of product in its lifecycle; 2) Organization's strategic performance criteria; 3) Reverse logistics processes functions required by the organization; and 4) Organization role of reverse logistics. While Efendigil *et al.* (2008) have proposed 12 criteria: 1) On-time delivery; 2) Fill rate; 3) Service quality; 4) Unit operation cost; 5) Capacity usage; 6) Total order cycle time; 7) System flexibility index; 8) Integration level; 9) Increment in market share; 10) Research & Development; 11) Environmental expenditure; and 12) Customer satisfaction.

In the context of sustainable SCs, except very few researches such as (Presley *et al.* 2007; Bai & Sarkis, 2010; Wittstruck & Teuteberg, 2011), substantial researches on 3PL selection did not explicitly considered the social and environmental criteria, in their decisional structure. Even in the area of material supplier selection, only the traditional criteria (price, quality, innovation, flexibility, financial stability…) and the green criteria (i.e. green design, pollution prevention, green image, green capability, and environmental management) were focused on (Akman (2015; Awasthi *et al.* 2011). Wittstruck & Teuteberg (2011) provided a holistic approach to select a recycling partner for German electrics and electronics industry. They suggested 9 sustainable criteria, namely: 1) Price; 2) Financial Capability; 3) Recycling Capability; 4) Quality of Recycling Processes; 5) Effective Implementation of Environmental Management Systems; 6) Standardized Health and Safety Conditions; 7) Sustainable Image; 8) Efficient Information Technology-Interfaces; and 9) Know-How in the field. While Presley *et al.* (2007) have proposed a decisional structure, in which 3 economic metrics (Net Present Value; Delivery performance; Supply chain cycle time), 3 environmental metrics (Waste generated, Improved compliance, % Product reclaimed), and 3 social metrics (Internal human resource, External population, and Stakeholders participation) represent the selection criteria of the reverse logistics outsourcing. Finally, Hosseini & Baker (2016) stress the importance of integrating the resilience concept in supplier selection problem. Resilience as defined by Sheffi (2005), which is the inherent ability of a system or organization to withstand the effect of a disruption (e.g. demand & supply risks, natural disasters, man made events, and business vulnerability), to maintain or recover its steady state behavior, thereby allowing it to continue normal operations after a disruptive event. So, Hosseini & Baker (2016) recommend to complete the decision structure of material supplier selection problem by the resilient criteria.

The present paper looks for enriching the logistics literature in the sense of identifying, categorizing, and determining the magnitudes of the main parameters impacting the 3PL selection, in the context of sustainable SCs. The Economic, social, and environmental criteria should be considered in the decision structure to select the most efficient candidate. The risk factors related to: Demand; Supply; Environment; Social Acceptability; and Outsourcing process himself affect seriously the efficiency and the stability (robustness) of the logistics process being outsourced, and should be considered in the decision structure. We consider the risk factors as extra resources and capabilities to maintain the efficiency of the logistics process, depending on the relative importance of each one. Doing so, an by mean of an appropriate evaluation method, the consistency and the robustness of the 3PL selection process will be achieved.

4.2.2. *Evaluation Methods*

In Aguezzoul (2014), the methods for evaluation and selection supplier can be classified into seven categories:

1) Linear weighting models: AHP / TOPSIS / ANP (Jayant *et al.* 2014; Dargi *et al.* 2014);

2) Mathematical programming models: Multi-objective programming / Goal programming / Data Envelopment Analysis DEA (Zhang *et al.* 2013; Karimi & Rezaeian, 2014; Mahdiloo *et al.* 2015);

3) Outranking Methods like ELECTRE (Vahdani *et al.* 2010) and PROMETHEE (Chen *et al.* 2011);

4) Artificial intelligence: Case Based Reasoning / Artificial Neural Network (Yan *et al.* 2003);

5) Methods Based on Costs: Activity Based Costing / Total Cost of Ownership (Bhutta & Huq, 2002);

6) Statistical approaches: Mean & Correlation matrix / Payoff matrix, Vendor profile analysis / Logistics Regression Model (McGinnis *et al.* 1995); and

7) Integrated approaches such as QFD-DEA (Karsak & Dursun, 2014); AHP-PROMETHEE (Bansal & Kumar, 2013); QFD-Fuzzy AHP (Ho *et al.* 2012).

According to Ho *et al.* (2010), the individual DEA method and the AHP-based methods seem to be the most prevalent ones;

Data Envelopment Analysis DEA is commonly used to compare the efficiency of a number of Decision Making Units DMUs (e.g. the 3PL candidates). It is a linear programming procedure for a frontier analysis of inputs and outputs (Charnes *et al.* 1978). Inputs represent the deployed resources and capability of the DMU, and the outputs represent the its performances, and the efficiency is the ratio of outputs to the inputs, the selected 3PL is the most *efficient* among the DMUs. (See analytical details in the next section, and the illustrative example). DEA has attracted more attention mainly because of: 1) can handle multiple tangible and intangible inputs and outputs; 2) its robustness, and can handle deterministic or stochastic inputs and outputs; and 3) doesn't require an assumption of a functional form of the efficiency (Ho *et al.* 2010). However, DEA presents some drawbacks: 1) The practitioners may be confused with input and output criteria. 2) the subjective assignment of ratings to intangible criteria may affect the value of the efficiency. 2) DEA is good at estimating "relative" efficiency of a DMU, but it converges very slowly to "absolute" efficiency. In other terms, DEA does not compare to a theoretical maximum; and 3) DEA is a nonparametric technique, and it cannot handle the relative importance attributed to each output or input, within the decision structure.

The wide applicability of AHP based methods is due their simplicity, ease of use, and great flexibility. The AHP hierarchy consists of evaluating the selection criteria, then evaluating the potential candidate relatively to those criteria. The candidates are ranked, and the most *effective* one is selected (Saaty, 1980). The integration of Quality Function Deployment QFD to AHP (Rajesh *et al.* 2011) allows to construct a coherent, and consistent relationship between the business strategies of the company and the selection criteria, by affecting the rights weights to the criteria. One of the issues in relation to the AHP method is the subjective judgments in pairwise comparison matrices. Fuzzy logic theory (Zadeh, 1965), and DEA method have been suggested to remedy to this inconvenience. Ho *et al.* (2012) proposed QFD-Fuzzy AHP, in which fuzzy triangular number have been utilized to capture the vagueness of judgments involved by a group of decision makers, when establishing pairwise matrix between business strategies and requirements, between requirements and criteria, and between criteria and supplier candidates. Authors such as Kuo & Lin (2012) have suggested ANP rather than AHP to capture the interdependency between the criteria, and introduced the DEA method to provide pairwise matrices without any reference to individuals' opinions.

In the context of sustainable SC, the question that has to be asked is: Do we seek for selecting the most effective 3PL candidate, or the most efficient one?

According to ISO definitions, in Frøkjær *et al.* (2000), *Effectiveness* is the accuracy and completeness with which users achieve certain goals. *Efficiency* is the relation between (1) the accuracy and completeness with which users achieve certain goals, and (2) the resources expended in achieving them.

According to Ho *et al.* (2010), the decision makers have to consider the resource limitations (e.g., budget of buyer and capacities of suppliers), when looking for an *efficient* supplier. Doing so, they will prevent oversizing the level of real needs, and therefore avoid incremental costs of idle resources and capabilities. In parallel, we think also, that they should consider the risk factors in their decision structure. Risk factors which are inherent to any environment business, involve additional resources and capabilities to remain *robust* in achieving the specific requirements. So, as has been advised by Anderson *et al.* (2011), the final choice of 3PL should be determined by specific levels of the selection criteria rather than a simple weighting of them by a linear weighting approach or similar.

In this paper, we propose an integrated approach to evaluate the 3PL suppliers, in the context of sustainable Supply Chains (SCs). The approach aims simultaneously to capture the *effectiveness* of AHP-based methods, the *efficiency* of DEA-based methods, and the *robustness* related to business risks mitigation: The DEA-QFD/Fuzzy AHP-Taguchi Robust Design approach; 1) DEA, for shortening the list of potential 3PL, by discarding the inefficient ones; 2) QFD-Fuzzy AHP , for determining the relative importance of selection criteria (e.g. resource & capability criteria, and the performance criteria), and the relative importance of the risk factors, in a consistent manner, according to the real logistics needs, and the business strategies; and 3) Taguchi Robust Design technique, for determining experimentally the Optimum of Taguchi; an "ideal 3PL" leading to the maximum of efficiency and robustness of the logistics being outsourced. So, the qualified 3PL candidates given by DEA are compared to the Taguchi optimum, and the winner will be the closest one to it.

To the best of our knowledge, it is the first time that orthogonal plan of Taguchi, which is often used in engineering process optimization, is combined with most the most popular supplier evaluation methods, to optimize the factors that influence the efficiency of selection process, in the context of sustainable SCs.

4.3. Methodology

The idea behind this approach is inspired from Taguchi's robust design experimental technique (Phadke, 1989), which is applied to optimize engineering processes. The technique consists to find the optimal design factor levels, that meeting the industrial process target, and making it less sensitive to variations of uncontrollable factors. The fundamental principle of robust design is to improve the quality of a product or a process by minimizing the effect of the cause of variation, without eliminating the causes themselves (Taguchi *et al.* 2000). Hereunder, we construct the decision structure by:

- Defining the logistics requirements, and business strategies;
- Modelling the logistics activity being outsourced;
- Identifying, categorizing, and defining the magnitudes of the factors influencing the selection decision; and

- Presenting the whole decision procedure.

4.3.1. Logistics requirements and business strategies

The logistics activities being outsourced, may be categorized into three categories: 1) Inbound logistics; 2) Outbound logistics; and 3) Reverse logistics. The activities concern the routine, standard, and customized services of the interfaces between respectively; Suppliers & Focal Company FC; FC & Customer zones; and Customer zones & FC. Depending on the industry sector, the scope and the complexity of the SC, and the business model of the FC, the Specific Requirements (SR) of Inbound; Outbound, and Reverse logistics can differ in nature and importance. The table **4.1** summarizes the generic logistical requirements of each logistics category, which are encountered in the literature (Sarkis *et al.* 2010; Srivastava, 2008; Li & Olorunniwo, 2008; Wu & Dunn, 1995). The list may be shortened or lengthened according to the industry sector, the positioning of the company, and the complexity of the SC.

According to Osterwalder (2004), business strategies of the FC may be grouped in nine business strategies (Sj): S1 Improve Value Proposition Product/Service; S2 Maintain Capabilities and Skilled Workforce; S3 Maintain long term Partnerships; S4 Reduce Costs by Sustainable Operations Practice; S5 Improve Market Share; S6 Maintain long term Customer Integration; S7 Improve Supply Chain performance; S8 Improve Image of the company; and S9 Maintain a superior Financial performance. The determination of the relative importance of business strategies, depends on the business model of the FC, and their weights are supposed given, in this paper.

4.3.2. Logistics activities as a business process

The logistics activities being outsourced are considered as a business process, which transforms resource and capability factors (e.g. Inputs) into performance factors (e.g. Outputs), while generating a value added. The process is submitted to uncontrollable factors (e.g. risk factors), which influence negatively the value added of the process. To characterize the process, we define two quality engineering functions: Efficiency & Robustness.

Table 4.1

Requirements of Inbound, Outbound, and Reverse Logistics

Logistics Process	Specific Requirements
Inbound logistics	SR1) Freight consolidation savings; SR2) Transportation cost reduction; SR3) Physical equipment; SR4) Information systems capabilities; SR5) Service level; SR6) Backhaul management; and SR7) Socially and environmentally responsible measures.
Outbound logistics	SR1) Shipment and product handling optimization; SR2) Consolidation distribution center; SR3) Increasing customer service; SR4) Appropriate logistical equipment; SR5) Distribution technologies to manage better the logistics system; SR6) Backhaul management; and SR7) Socially and environmentally responsible measures.
Reverse Logistics	SR1) Optimal recovery plan for portfolio of returns; SR2) Storage space and appropriate storage conditions; SR3) Reducing packaging wastes and reuse packaging Materials; SR4) Operational cost controls and asset recovery; SR5) Increasing customer satisfaction; SR6) Providing valuable customer data to product design improvement; and SR7) Information Technology to improve the visibility into the returns in motion; and SR8) Socially and environmentally responsible measures.

In general, it is very difficult to specify a technical efficiency function for a service process, and the more complex the process, the less accurate is the efficiency function likely to be (Farrell, 1957). In this paper, the Efficiency is approached by a rational function, in which the numerator is the linear combination of outputs, and the denominator is the sum of linear combination of inputs, and the linear combination of risk factors. The linear factor of each factor represents its relative importance related to the logistics requirements & business strategies.

The Robustness is the Taguchi loss function; a quadratic function which penalizes any deviation of a factor design (e.g. input or output) from its specification value, and contributes to deteriorating the whole performance of the process (Wysk *et al.* 2000). In Phadke (1989), three types of loss functions are defined by Taguchi: A two-side loss function referred to as "The nominal is the best", where a nominal value is the target and a deviation from either sides of the target are allowed as long as it remains within specification limits; and One sided-functions referred to as "Larger is better" and "Smaller is better", where a deviation from the target is allowed only in one direction. In our case, as the efficiency function is the target, which we desire to maximize, the "Larger is the best" is the appropriate loss function, needed to optimize.

The analytical expressions of Efficiency, and Robustness are presented in the illustrative example, and the figure **4.1** illustrates the logistics activities being outsourced as a business process. Hereunder, we identify, categorize, and determine the magnitudes of each decision factor.

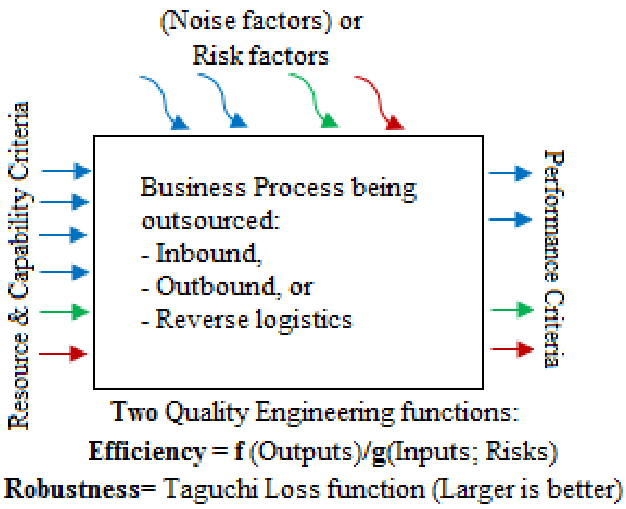

Fig.4.1. Logistics activities being outsourced as a business process

4.3.3. Sustainable criteria & Risk factors

Based on their empirical study of 340 users of 3PLs, Coltman *et al.* (2011), concluded that the factors which are potentially important in the 3PL selection, may be categorized into five classes: 1) Account management (i.e. accuracy, flexibility, transparency); 2) Internal factors; 3) External factors; 4) Customer charge (i.e. Parity price, surcharge options in contract), and 5) Performance factors. In a past publication, Franceschini & Rafele, (2000) had argued that external factors are just a mirror of internal ones to satisfy the customer requirements. In this paper, we introduce the account management, and customer charge factors within both the internal and performance factors to align with the Robust Design Approach.

To implement Taguchi Robust design, two types of parameters should be identified: 1) Control factors and Noise factors. In this paper, Control factors are those sustainable criteria, which the logistics process designer can easily control, and Noise factors or business risk factors are the disturbing factors which are impossible or too expensive to control by the designer. We divided Control factors into two categories, 1) The so-called Internal factors, which describe in to which extent a potential 3PL provider utilizes resources, and deploys capabilities to satisfy the customer's requirements, and 2) The so-called Performance factors, which rather describe the results of some combined resources deployed to reach them.

From relevant logistics empirical studies such as Coltman *et al.* (2011), and Anderson *et al.* (2011), and from recent papers such as Hosseini & Baker (2016); Jayaram & Tan, (2010); Lee & Kim (2009); and Presley *et al.* (2007), we suggest as Control factors: 6 internal factors, and 4 performance factors:

- *Internal factors*: **A**) Scope of resources; **B**) Parity price; **C**) Professionalism; **D**) Customer service recovery; **E**) Environmental practice; and **F**) Social practice.
- *Performance factors*: **G**) Reliable performance delivery; **H**) Supply chain capacity; **I**) Environmental impacts; and **J**) Social performance.

In Jüttner (2005), SC risk sources are variables that cannot be predicted with certainty, and from which disruptions can emerge. They may be classified into five categories: Environmental risk sources, demand and supply risk sources, process risk sources and control risk sources. We suggest as Noise factors:

- **K**) Uncertainty and variability; **L**) Natural environmental risks; **M**) Social risks; and **N**) Lack of control on quality of product/service provided by the 3PL provider.

Indicators are needed to quantify the extent to which criteria or risks are met. We adopt 4 levels (1= Low; 2= Medium; 3= High; and 4= Very High) for each criterion, except the scope of resources, for which we suggest two levels (2= Medium; and 3= High), and we adopt 3 levels of criticality for the risk factors (Low; Medium; and High). According to the 9's scale, we attribute the magnitudes as follows:

- Internal factors: (Low = 9; Medium = 7; High = 5; and Very High = 3);
- Performance factors: (Low = 3; Medium = 5; High = 7; and Very High = 9); and

- Risk factors: (Low = 9; Medium = 7; and High = 5);

The table **4.2** summarizes the indicator sets of internal and performance factors, their definitions and the significance of different levels.

4.3.4. Structure of the decision process

Our robust integrated approach may be structured into three distinguished phases, which are summarized in the table **4.3**;

Table 4.2

Sustainable criteria & calibration

Criteria definitions	Qualified levels of criteria	
G. Reliable performance delivery (delivery in full, on time and error free):	98–100% of the time	**4**
	95– 97% of the time	**3**
	92– 94% of the time	**2**
	89– 91% of the time	**1**
H. Supply chain capacity: The capacity to meet unanticipated customer needs. Includes conducting special pickups, crossdocking, seasonal warehousing.	Excellent: industry leader;	**4**
	Better than industry average;	**3**
	Equal to industry average;	**2**
	Below industry average	**1**
D. Customer service recovery: Activity aimed at identifying and resolving unexpected service delivery problems.	Very proactive: an industry leader;	**4**
	Better than industry average response;	**3**
	Equal to industry average response;	**2**
	Slow to respond to problems and unlikely to propose solutions	**1**
A. Scope of resource: Hard and soft assets owned or controlled by the 3PL provider to deploy for achieving the expected outcome	Better than industrial average deployment;	**3**
	Equal to industrial average deployment;	**2**
C. Professionalism: It relates to the logistics service provider's knowledge of the logistics industry AND the customer's business. For example, logistics industry level professionalism would include knowledge of how to handle customs, transportation, warehousing and any other required logistics activities	Deep knowledge of both logistics and customer's business;	**4**
	Deep knowledge of logistics and acceptable knowledge of customer's business	**3**
	Acceptable knowledge logistics and deep knowledge of customer's business	**2**
	Acceptable knowledge of both logistics and customer's business	**1**

B. Price Parity: Is what the outsourcing company pays for the service and/ or product provided by 3PL provider?	Significantly higher than what you pay (+5 to 8%)	**1**
	Higher than what you currently pay (+0 to 4%)	**2**
	Similar to what you currently pay;	**3**
	Lower than what you currently pay (0–4% less)	**4**
E. Environmental Practice: The extent to which the 3PL deals with environmental issues	End-Of-Pipe technologies	**1**
	Clean technologies	**2**
	Life cycle thinking	**3**
	Carbon footprint management	**4**
I. Environmental impacts: The tangible arguments demonstrating commitment to the environmental concerns	Legal requirement & Standards Compliance	**1**
	Environmental certification	**2**
	Environmental performances	**3**
	Carbon footprint disclosure	**4**
F. Social Practice: The extent to the 3PL Provider deals with social issues	Human right/Labour management	**1**
	Occupational Health and Safety	**2**
	Skill management	**3**
	Local community concerns	**4**
J. Social Performance: The tangible arguments demonstrating commitment to the social concerns	Compliance with standards of integrity and responsibility	**1**
	Certified OHSAS 18001	**2**
	Job stability	**3**
	SA 8000 / ISO 26000 Management system	**4**

4.4. Illustrative example

Suppose that a Focal Company FC within a SC decides to outsource its reverse logistics activities, and look for an efficient 3PL to vehicle the sustainable practices between the partners of the SC.

After making a tender, and receiving applications, it obtained a list of 14 (3PLs) which satisfy the qualified level of each selection criterion (See in the table **4.4** the 3PL evaluation, according to each criterion).

The FC proceeds to DEA method to shorten the list of qualified 3PLs to only those of comparable relative efficiencies.

Then, FC performs a two-stage QFD-Fuzzy AHP to prioritize the criteria, and the risks factors.

Table 4.3

The detailed steps of the robust integrated selection approach

Phase 1	
Step1:	Define the logistics process to outsource, and list the real requirements to be fulfilled;
Step2:	Establish and validate the list of sustainable criteria for selecting 3PL. Separate them in terms of resource & capability criteria, and performance criteria. Define for each criterion the indicators, and corresponding magnitudes on a scale of 1 to 9;
Step3:	Make a tender for outsourcing the process while specifying the requirements, and receive applications;
Step4:	Eliminate candidates not satisfying the qualification level of selection criteria;
Step5:	Reduce the list of candidates by classifying their relative efficiencies. The efficiencies are obtained by performing the linear programming of Data Envelopment Analysis, in any available commercial software.
Phase 2	
Step6:	Determine consistently the relative importance of each selection criterion, and take into account the alleged inaccuracy induced by the judgment of the group of decision making. A two-stage QFD-Fuzzy AHP is performed to deploy Business Strategies into Specific Requirements of logistics, then Specific Requirements into Selection Criteria.
Step7:	Like the step 6, determine the relative importance of each of the four risk factors: Natural environment risk; Social Risk; Uncertainty of supply and demand risk, and Outsourcing risk, according to Specific Requirements of logistics
Phase 3	
Step8:	Adopt the appropriate orthogonal plan of Taguchi, according to the number of criteria, the number of risk factors, and their corresponding number of indicators
Step9:	Define the efficiency to the logistics process being outsourced, and the corresponding Taguchi function (the robustness of logistics process);
Step10:	Find the Optimum of Taguchi, which maximize both the efficiency, and the robustness, by performing the experiments within the orthogonal plan;
Step11:	Compute within the orhogonal plan the efficiency, and the robustness of each 3PL candidate, and select the closest one to the optimum of Taguchi; and
Step12:	Start the negociations of contract with the winner

Decision makers look for an appropriate parameter design layout to perform Taguchi technique. The result will be the determination of Taguchi optimum, a '' virtual 3PL'' showing the optimal levels of criteria leading simultaneously to the highest efficiency, and the lowest Taguchi loss function.

Finally, all the preselected 3PLs will be compared within the layout of Taguchi, and the winner should be the closest one to the optimum of Taguchi.

Hereunder, we present the analytical models of the evaluation methods, and construct progressively the integrated approach of 3PL selection, by showing their limitations.

4.4.1. DEA-method

Data Envelopment Analysis, is a linear programming procedure for a frontier analysis of inputs and outputs. DEA assigns a score of 1 to a unit only when comparisons with other relevant units do not provide evidence of inefficiency in the use of any input or output. DEA assigns an efficiency score less than one to "relatively" inefficient units.

Data Envelopment Analysis model may be used to evaluate all the qualified suppliers, and eliminate the less efficient ones. Ten evaluating factors are considered in the model, in which 6 inputs are related to the supplier resource & capability A; B; C; D; E; &F, and 4 outputs G; H; I; & J are related to the supplier performance.

The relative efficiency 'ε_j" of each supplier ($3PL_j$) is computed by running the following linear program:

** For each ($3PL_j$) candidate:

Minimize ε_j (1)

S/t

$\sum_i \omega_i.X_i \leq \varepsilon_j.X_j$; (2)

$\sum_i \omega_i.Y_i \geq Y_j$; (3)

$\omega_i \geq 0$; (4)

Where:

X_i : The vector of inputs in $3PL_i$

Y_i : The vector of outputs in $3PL_i$, corresponding to X_i :

X_j : The vector of inputs of $3PL_j$ for which we want to determine its efficiency

Y_j : The vector of outputs of $3PL_j$

ω_i : Non-negative variables expressing the weight given to $3PL_i$ in its efforts to dominate $3PL_j$

ε_j : The efficiency of $3PL_j$

We consider the 14 qualified 3PL suppliers, and run for each one the DEA program in LINDO software. We present the relative efficiencies of the potential candidates in the table **4.4**. The figure **4.2** shows the program implementation for TP_{14}, with a relative efficiency equal to **0.714**.

Table 4.4

Evaluation of the qualified candidates by DEA implementation

Qualified Suppliers	Resource & Capability Criteria						Performance Criteria				Relative Efficiency of Supplier
	A	B	C	D	E	F	G	H	I	J	
3PL1	5	5	7	9	3	5	9	7	3	5	1.000
3PL2	5	5	5	5	9	7	5	5	9	5	1.000
3PL3	5	5	5	5	7	9	5	5	7	7	1.000
3PL4	7	5	7	9	5	7	7	7	5	7	1.000
3PL5	7	5	7	9	9	5	7	7	7	5	1.000
3PL6	7	3	9	7	9	7	7	7	7	7	1.000
3PL7	7	7	7	7	7	7	7	9	5	7	1.000
3PL8	5	3	5	5	5	5	5	7	5	5	1.000
3PL9	5	5	3	7	3	3	5	3	3	5	1.000
3PL10	7	7	5	7	7	5	5	5	3	3	0.816
3PL11	7	5	9	7	7	5	5	5	5	3	0.875
3PL12	5	5	7	7	7	7	5	5	5	5	0.849
3PL13	7	9	7	7	7	7	3	3	5	5	0.714
3PL14	7	5	7	7	7	7	3	5	5	5	**0.714**

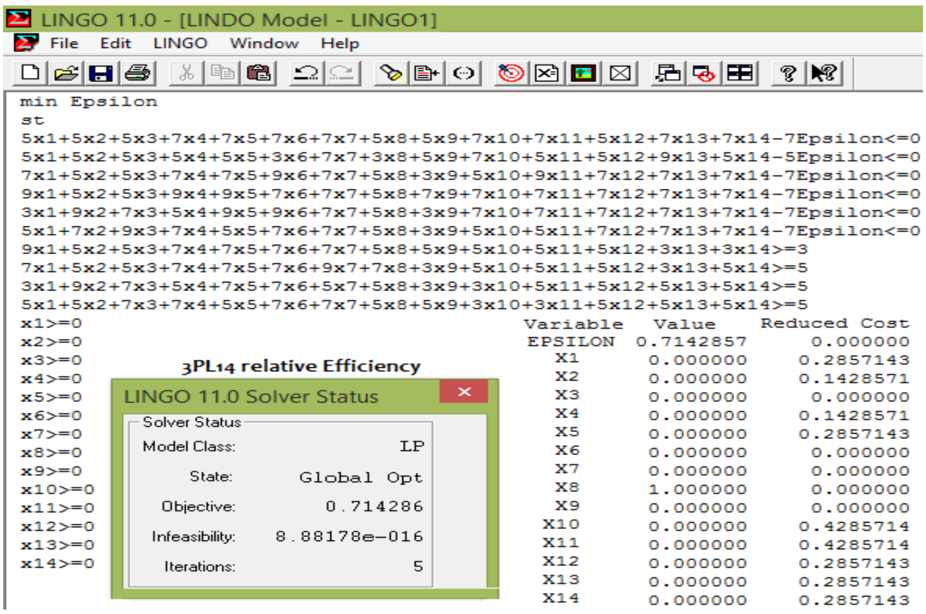

Fig.4.2. Implementation of DEA program to find the relative efficiency of $3PL_{14}$

We see that nine 3PLs are still in the competition, with relative efficiency equal to 1, and need to be classified. As has been mentioned in the section 4.2, the DEA method is a non-parametrized linear programming method, which does not care to relative importance of the decision factors. It leads only to refine the list of 3PL candidates, into those of comparative efficiencies, and requires integration with another decision tool for being effective.

4.4.2. QFD-based methods

4.4.2.1. QFD method

In Akao & Mazur, (2003), Quality Function Deployment QFD is a structured method leading to deploy the identified and prioritized customer's Requirements (e.g. "Whats") into features of product or service (e.g. "Hows"). It refers to a matrix called House of Quality HoQ, in which the decision makers may identify the level of relationship between each "What" and each "How". Usually, the relationships are measured by a 9-point scale: 1 (very low); 3 (low); 5 (moderate); 7 (high); and 9 (very high).

The HoQ matrix may be empowered by adding other important information, such as correlations between the "Whats", and correlations between the "Hows" (Chan & Wu, 2005), to consider the interdependency between the parameters. In this paper, this consideration was not taken, for the reason of simplification.

In our illustrative example, one may directly perform the QFD method to classify the nine 3PL candidates (e.g. "Hows"), according to the selection criteria (e.g. "Whats"). Assume at the moment, that the weights of criteria are known (A: 0.11; B: 0.09; C: 0.10; D: 0.09; E: 0.13; F: 0.09; G: 0.12; H: 0.11;
I: 0.10; and J: 0.06). The deployment of the criteria into the 3PL candidates leads to the HoQ in the table **4.5**.

The rating of the candidates could be as follows: $3PL_6 \succ 3PL_7 \succ 3PL_5 \succ 3PL_4 \succ 3PL_2 \succ 3PL_3 \succ 3PL_1 \succ 3PL_8 \succ 3PL_9$; and consequently, the winner would be $3PL_6$ followed by $3PL_7$

However, the information which appears within the HoQ comes from subjective value judgments of the decision makers involved in the selection process. This may challenge the consistency of the decision, notably if the number of 3PL candidates is large enough. Moreover, the perception of decision makers may be vague due to their different disciplines. For instance, a judgment “moderate” for the operations’ manager can mean a judgment “high” or “low”, for the purchasing & logistics manager. So, the drawbacks of inconsistency & vagueness need to be overcome.

Table 4.5

Ranking 3PLs by direct QFD (‘Whats’= Sustainable criteria versus ‘Hows’= 3PL candidates)

QFD method		**3PL1**	**3PL2**	**3PL3**	**3PL4**	**3PL5**	3PL6	**3PL7**	**3PL8**	**3PL9**
Selection Criteria	Criteria Weights									
A	0.11	5	5	5	7	7	7	7	5	5
B	0.09	5	5	5	5	5	3	7	3	5
C	0.10	7	5	5	7	7	9	7	5	3
D	0.09	9	5	5	9	9	7	7	5	7
E	0.13	3	9	7	5	9	9	7	5	3
F	**0.09**	**5**	**7**	**9**	**7**	**5**	**7**	**7**	**5**	**3**
G	0.12	9	5	5	7	7	7	7	5	5
H	0.11	7	5	5	7	7	7	9	7	3
I	0.10	3	9	7	5	7	7	5	5	3
J	0.06	5	5	7	7	5	7	7	5	5
Linear sum		10.36	10.66	10.50	12.88	13.30	13.44	13.36	9.60	8.68
Weights		**0.101**	**0.104**	**.102**	**0.125**	**0.129**	**0.131**	**0.130**	**0.093**	**0.084**
3PL rank		7	5	6	4	3	**1**	2	8	9

4.4.2.2. QFD-AHP method

To capture the problem of consistency, authors such as Rajesh et al. (2011) have suggested to empower QFD method by integrating Analytic Hierarchic Process AHP (Saaty, 1980). In AHP, the decision-makers are asked to compare the “Hows”, with regards to a given “What”. For instance, comparing the 3PL candidates, according to the social practice criterion “J” allows to construct the comparison matrix A:

$$
A=\begin{pmatrix}
1 & \frac{1}{3} & \frac{1}{5} & \frac{1}{3} & 1 & \frac{1}{3} & \frac{1}{3} & 1 & 3 \\
3 & 1 & \frac{1}{3} & 1 & 5 & 1 & 1 & 3 & 5 \\
5 & 3 & 1 & 3 & 5 & 3 & 3 & 5 & 7 \\
3 & 1 & \frac{1}{3} & 1 & 3 & 1 & 1 & 3 & 5 \\
1 & \frac{1}{5} & \frac{1}{5} & \frac{1}{3} & 1 & \frac{1}{3} & \frac{1}{3} & 1 & 3 \\
3 & 1 & \frac{1}{3} & 1 & 3 & 1 & 1 & 3 & 5 \\
3 & 1 & \frac{1}{3} & 1 & 3 & 1 & 1 & 3 & 5 \\
1 & \frac{1}{3} & \frac{1}{5} & \frac{1}{3} & 1 & \frac{1}{3} & \frac{1}{3} & 1 & 3 \\
\frac{1}{3} & \frac{1}{5} & \frac{1}{7} & \frac{1}{5} & \frac{1}{3} & \frac{1}{5} & \frac{1}{5} & \frac{1}{3} & 1
\end{pmatrix}
$$

The dominant Eigen value λ^A_{max} of A, may be determined by means of the so-called Power method:

Let B be the power matrix; **B= (bij)=A^K**

Let W be the vector, with components wi are expressed by the terms bij as follows:

$$\mathbf{w_i} = \frac{\sum_j \mathbf{b_{ij}}}{\sum_{i,j} \mathbf{b_{ij}}} \tag{5}$$

The Rayleigh's (1842–1919) quotient provides a good approximation of the dominant Eigen value λ^A_{max} of the matrix A, as follows:

$$\lambda^A_{max}.W \approx A.W \tag{6}$$

$$W^T.\lambda^A_{max}.W \approx W^T.A.W$$

$$\lambda^A_{max} \approx \frac{W^T.A.W}{W^T.W} \tag{7}$$

The vector W approaches the dominant Eigen vector of A, as the power K increase. In our calculation, *K*=4

W^T = (0.05, 0.14, 0.30, 0.13, 0.05, 0.13, 0.13, 0.05, 0.02)

The consistency Ratio CR is used to control results of the AHP method. It allows directly estimating the consistency of the pairwise comparison.

$$CR = \frac{CI}{RI} \tag{8}$$

Where CI is the Consistency Index, calculated by:

$$CI = \frac{\lambda_{max}^{A} - n}{n - 1} \quad (9)$$

n is the dimension of A, and RI *is* the Random Index value given by the table **4.6**

CR must be less than 0.10 (Saaty, 1980).

So, the vector (5, 7, 9, 7, 5, 7, 7, 5, 3) corresponding to the deployment of social practice F into 3PL candidates by using direct QFD method (see table **4.5**) is replaced by the vector W^T = (0.05, 0.14, 0.30, 0.13, 0.05, 0.13, 0.13, 0.05, 0.02) found by integrating AHP to QFD. The same procedure is applied to the remainder criteria, to obtain a refined HoQ, and this leads to correct the rating of the 3PLs as follows (see table **4.7**):

$$3PL_6 \succ 3PL_7 \succ 3PL_5 \succ 3PL_4 \succ$$
$$3PL_1 \succ 3PL_2 \succ 3PL_3 \succ 3PL_8 \succ 3PL_9$$

4.4.2.3. QFD-Fuzzy AHP method

To catch up the vagueness of judgments within the comparison matrix A, a fuzzy set approach of Zadeh (1965) may be used by expressing the linguistic values of decision makers, in trapezoidal or triangular fuzzy numbers. For instance, each judgmental value in the 9's scale may be replaced by a triangular fuzzy number $\tilde{N}(a,b,c)$, where $a \le b \le c$

For any $\tilde{N}(a,b,c)$, we can associate a triangular-type membership function $\mu F_{\tilde{N}}(x)$, defined as follows:

$$\mu F_{\tilde{N}}(x) = \begin{cases} 0, \text{if } x \prec a \text{ or } x \succ c \\ \frac{x-a}{b-a}, \text{if } a \le x \le b \\ \frac{c-x}{c-b}, \text{if } b \le x \le c \end{cases} \quad (10)$$

The figure **4.3** illustrates the membership functions of the fuzzy triangular numbers $\tilde{1}(0,1,3)$, $\tilde{3}(1,3,5)$, $\tilde{5}(3,5,7)$, $\tilde{7}(5,7,9)$, and $\tilde{9}(7,9,11)$

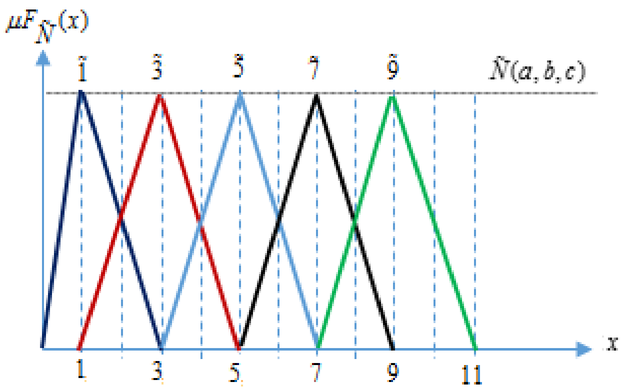

Fig. 4.**3** Triangular membership functions of triangular fuzzy numbers

By using the α_cut representation of Kwong & Bai (2004), the triangular fuzzy number $\tilde{N}(a,b,c)$ can be characterized only with two components:

$$\tilde{N}(a,b,c) = [\alpha.(b-a)+a;\alpha.(c-b)+c] \quad (11)$$

The reverse number of $\tilde{N}(a,b,c)$ is defined as:

$$\tilde{N}^{-1}(a,b,c) = \left[(\alpha.(b-a)+a)^{-1};(\alpha.(c-b)+c)^{-1}\right] \quad (12)$$

Lee (1999) has suggested a linear convex combination to approximate a fuzzy triangular number with only one component. So one may perform Fuzzy AHP like the traditional AHP, by replacing the 1-9 scale numbers in the comparison matrix A, with the approximate fuzzy triangular numbers, in the equation (13)

$$\mathbf{\tilde{N}(a,b,c) = [(1\text{-}\mu).(\alpha.(b\text{-}a)+a)+\mu.(\alpha.(c\text{-}b)+c)]} \quad (13)$$

Where μ is the index of Optimism

For α_cut = μ = 0.5

$\tilde{1}(0,1,3) = 1.5 \,\&\, \tilde{1}^{-1}(0,1,3) = 0.75$

$\tilde{3}(1,3,5) = 3 \,\&\, \tilde{3}^{-1}(1,3,5) = 0.375$

$\tilde{5}(3,5,7) = 3 \,\&\, \tilde{5}^{-1}(3,5,7) = 0.208$

$\tilde{7}(5,7,9) = 7 \,\&\, \tilde{7}^{-1}(5,7,9) = 0.146$

$\tilde{9}(7,9,11) = 9 \,\&\, \tilde{9}^{-1}(7,9,11) = 0.110$

Table 4.6

List of Saaty's Random indices RI

Dim n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	-	-	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Table 4.7

Ranking 3PL alternatives by using QFD/AHP (Whats= Sustainable criteria versus Hows= 3PL alternatives)

QFD/AHP		3PL1	3PL2	3PL 3	3PL4	3PL5	**3PL6**	3PL7	3PL8	3PL9	Consistency Ratio CR
Selection Criteria	Criteria Weights										
A	0.11	.06	.06	.06	.18	.18	.18	.18	.06	.06	-
B	0.09	.11	.11	.11	.11	.11	.04	.27	.05	.11	.04
C	0.10	.13	.05	.05	.13	.13	.30	.13	.05	.02	.01
D	0.09	.21	.04	.04	.21	.21	.09	.09	.04	.09	.01
E	0.13	.02	.22	.10	.05	.22	.22	.10	.05	.02	.02
F	0.09	**.05**	**.14**	**.30**	**.13**	**.05**	**.13**	**.13**	**.05**	**.02**	**.02**
G	0.12	.30	.05	.05	.13	.13	.13	.13	.05	.05	.01
H	0.11	.12	.05	.05	.12	.12	.12	.27	.12	.02	-
I	0.10	.03	.32	.15	.06	.15	.15	.08	.05	.03	.03
J	0.06	.06	.06	.18	.18	.06	.18	.18	.06	.06	-
Weights of 3PL		0.112	0.110	.101	0.122	0.144	0.155	0.152	0.058	0.046	
3PL rank		5	6	7	4	3	**1**	2	8	9	

The implementation of QFD Fuzzy-AHP method leads to a new HoQ in the table **4.8**, with the 3PL rating as follows:

$$3PL_7 \succ 3PL_6 \succ 3PL_5 \succ 3PL_4 \succ$$
$$3PL_2 \succ 3PL_1 \succ 3PL_3 \succ 3PL_8 \succ 3PL_9$$

Now, let us find the weight of the selection criteria, which we assume given when running QFD method, and the weights of risk factors needed by the integration of Taguchi Robust Design:

The 9 Business strategies with known weights are deployed into the 8 specific requirements of reverse logistics (see table **4.9**);

The 8 Specific requirements are deployed into 10 selection criteria (see table **4.10**); and

The 8 Specific requirements are deployed into 4 risk factors (see table **4.11**);

Table 4.8

Ranking 3PL alternatives by using QFD/Fuzzy AHP (Sustainable criteria versus 3PL alternatives)

QFD/Fuzzy AHP		**3PL1**	**3PL2**	**3PL3**	**3PL4**	**3PL5**	**3PL6**	3PL7	**3PL8**	**3PL9**	**Consist. Ratio CR**<0.1
Selection Criteria	Criteria Weights										
A	0.11	.05	.06	.06	.15	.17	.18	.19	.07	.07	.05
B	0.09	.09	.10	.10	.11	.12	.04	.27	.04	.13	.05
C	0.10	.12	.05	.05	.13	.14	.29	.15	.05	.02	.05
D	0.09	.19	.03	.04	.21	.23	.08	.09	.04	.09	.05
E	0.13	.02	.19	.10	.05	.22	.24	.11	.05	.03	.06
F	0.09	.05	.12	.29	.13	.05	.13	.15	.06	.02	.05
G	0.12	.29	.04	.05	.11	.13	.13	.15	.05	.05	.05
H	0.11	.10	.05	.05	.11	.12	.13	.28	.14	.02	.05
I	0.10	.02	.31	.11	.06	.15	.16	.06	.07	.03	.05
J	0.06	.05	.06	.15	.17	.06	.18	.19	.07	.07	.05
Weights of 3PL		0.101	0.104	.098	0.117	0.145	0.159	0.162	0.064	0.050	
3PL rank		6	5	7	4	3	2	**1**	8	9	

Table 4.9

QFD1-Fuzzy AHP: Business strategies S_i versus logistics requirements SR_j

HOQ1	Importance of strategies	Specific logistics requirements (for Reverse logistics)								CR<0.1
		SR_1	SR_2	SR_3	SR_4	SR_5	SR_6	SR_7	SR_8	
S_1	.100	.052	.023	.048	.114	.393	.222	.044	.105	.058
S_2	.100	.171	.032	.029	.070	.064	.156	.143	.334	.054
S_3	.100	.072	.156	.027	.143	.114	.052	.122	.315	.067
S_4	.150	.286	.056	.131	.052	.120	.047	.043	.263	.050
S_5	.050	.156	.030	.028	.071	.447	.065	.060	.143	.059
S_6	.120	.079	.023	.041	.022	.312	.286	.077	.159	.064
S_7	.130	.056	.052	.047	.131	.289	.043	.120	.263	.050
S_8	.050	.049	.045	.041	.038	.220	.112	.102	.392	.053
S_9	.200	.311	.020	.081	.285	.157	.038	.035	.074	.060
Weights of requirements	SR (j)	**.311**	**.047**	**.061**	**.123**	**.215**	**.106**	**.077**	**.210**	-

Table 4.10

QFD2- Fuzzy AHP: Specific logistics requirements SR_j versus Selection criteria

HOQ 2	Importance rating of *SRj*	Resource & Capability Criteria (Inputs)						Performance Criteria (Outputs)				CR<0.1
		A	B	C	D	E	F	G	H	I	J	
SR_1	.161	.098	.220	.044	.041	.038	.040	.205	.191	.091	.032	0.052
SR_2	.047	.246	.120	.051	.023	.112	.048	.022	.230	.104	.045	0.052
SR_3	.061	.039	.096	.090	.084	.333	.078	.018	.036	.190	.034	0.055
SR_4	.123	.143	.061	.269	.135	.057	.054	.101	.095	.044	.041	0.051
SR_5	.215	.106	.048	.099	.215	.045	.042	.200	.186	.021	.039	0.031
SR_6	.106	.062	.024	.058	.054	.287	.149	.139	.050	.130	.047	0.052
SR_7	.077	.352	.211	.117	.057	.027	.026	.109	.053	.024	.022	0.056
SR_8	.210	.045	.042	.089	.021	.206	.192	.020	.039	.179	.167	0.049
Weights Criteria	w_j	**.113**	**.092**	**.103**	**.090**	**.124**	**.087**	**.118**	**.113**	**.094**	**.065**	-

Table 4.11

QFD3- Fuzzy AHP: Specific logistics requirements SR_j versus risk factors

HOQ 3	Importance rating of requirements *SR_j*	Risk factors				Consistency Ratio CR<0.1
		K	L	M	N	
SR_1	.161	.459	.051	.104	.386	0.064
SR_2	.047	.120	.558	.057	.265	0.080
SR_3	.061	.108	.549	.091	.252	0.071
SR_4	.123	.509	.081	.223	.187	0.078
SR_5	.215	.459	.051	.104	.386	0.064
SR_6	.106	.178	.043	.150	.629	0.082
SR_7	.077	.062	.052	.221	.664	0.081
SR_8	.210	.459	.051	.104	.386	0.064
Weights of risk Factors	r_k	**.367**	**.108**	**.130**	**.395**	-

4.4.3. Taguchi Robust Design Technique

Business uncertainties are unexpected factors, which are inherent to any industrial system or process. Risk management has the responsibility to identify the risk factors, to revise periodically their criticality, and to suggest corrective and preventive actions to eliminate them. So, to keep more resilient a process such as logistics, additional resources, capabilities, and capacities should be attributed, according to the relative importance of each risk factor, and the budget limitation of the company. The most *effective* 3PL is the one which oversize the levels of its resources & capabilities to achieve the logistics requirements of its customer. As we show, QFD-Fuzzy AHP methodology can classify the 3PL candidates according to their effectiveness.

However, by oversizing somewhat the levels of resources, capabilities, and capacities does not ensure maintaining the high *efficiency* of the process being outsourced. To do so, one should look for integrating a tool, which is able to determine the optimal levels of parametrized selection factors, which maximize the efficiency with less variation caused by the impervious factors.

In Phadke (1989), the idea behind robust design is to improve the quality of a product or a process by minimizing the effects of variation, without eliminating the causes (since they are too difficult or too expensive to control). To measure quality, Taguchi defines two quality engineering functions:

1) The target function; and

2) Quality Loss Function.

The first one is a quality characteristics of the process (i.e. Mechanical resistance of a product; ratio of outputs to inputs…). The second is the Quality Loss function (e.g. Robustness), which penalizes any deviation of a factor design from its specification value and contributes to deteriorating the whole performance of the process (Wysk *et al.* 2000). Depending on the target, Taguchi has defined three types of loss functions: A two-side loss function referred to as ''*The nominal is the best*'', where a nominal value is the target and a deviation from either sides of the target are allowed as long as it remains within specification limits; and One sided-functions referred to as ''*Larger is better*'' and ''*Smaller is better*'', where a deviation from the target is allowed only in one direction.

Thus, we integrate Taguchi Robust Design to DEA-QFD/Fuzzy AHP, to provide a robust integrated approach for selecting a 3PL supplier, in the context of Sustainable SCs. Hereunder, we illustrate the main phases of Taguchi technique;

4.4.3.1. Orthogonal plan of Taguchi

To implement robust design, Taguchi advocates the use of an "inner array" and "outer array" approach. The "inner array" consists of the Orthogonal Array that contains the control factor (e.g. selection criteria A, B… J) settings; the "outer array" consists of the Orthogonal Array that contains the noise factors (e.g. risk factors K, L, M, N) and their settings, which are under investigation. The combination of the "inner array" and "outer array" constitutes what is called the "complete parameter design layout". The product array is used to systematically test various combinations of the control factor settings over all combinations of noise factors, after which the mean response (e.g. mean Efficiency), and corresponding Signal-to-Noise Ratio (e.g. Taguchi loss function) may be approximated for each run using the following equations:

$$E_{nm} = \frac{\sum_j w_j . X_{jn}}{\sum_i w_i . X_{in} + \sum_k r_k . X_{knm}} \qquad (14)$$

Where:

E_{nm} : Dimensionless rational function expressing the efficiency of the logistics process, corresponding to the experiment n et the risks' configuration m

w_j : Weight of performance criterion j, given by multi-stage QFD-Fuzzy AHP

r_k : Weight of risk factor k, given by multi-stage QFD-Fuzzy AHP

X_{jn} : Attribute of performance criterion j, corresponding to the experiment n

X_{in} : Attribute of resource & capability criterion i, corresponding to the experiment n

X_{knm} : Attribute of risk factor k, within the risk configuration m, and corresponding to the experiment n

$$\mathbf{SNR_n = -10.log}\left[\frac{1}{M}.\sum_{m=1}^{M}\frac{1}{(E_{nm})^2}\right] + \underbrace{\mathbf{20.log}\sum_{n=1}^{N}E_n}_{\text{Standard factor}} \quad (15)$$

Where:

SNR_n : Signal-to—Noise Ratio expressed, and standardized in decibel scale, corresponding to the experiment n

N.B. The ‘‘Larger is the best’’ is the appropriate loss function needed to maximize, in our case. The standard term is added to avoid working with negative values.

E_n = $\frac{\sum_m E_{nm}}{M}$: The mean efficiency of the all configurations of risk factors

M&N: Respectively, the number of experiments and the number of risk configuration for each experiment, within the complete parameter design layout of Taguchi

Each control factor is to be tested at 4 levels, except the factor A which is to be tested at 2 levels. While each noise factor is tested at 3 levels.

Following Taguchi's method, two experimental designs are selected to vary the control factors, and the noise factors. An L32b (4, 2) orthogonal array is selected for the controllable factors while an L9 (3) orthogonal array is chosen for the noise factors.

(http://www.york.ac.uk/depts/maths/tables/orthogonal.htm).

The total number of experiments required is only N=32, and each experiment is done for M=9 configurations of risk factors (See table **4.12**). The preferred parameter settings are then determined through analysis of both the “Mean Efficiency”, and “Signal-to-Noise Ratio” (SNR).

4.4.3.2. Interpretation

For a given criterion *i*, and for each level *j* of the criterion, we compute the product $P_{ij} = E_{ij} * SNR_{ij}$: “average of efficiency” * “Signal-to-Noise Ratio”.

For example, the value of P_{B1} for the level 1 (with attribute 9) of the criterion B, is computed as follows (see the table **4.12**):

E_{B1} = (0.12 + 0.44 + 0.34 + 0.49 + 0.30 + 0.26 + 0.30 + 0.29)/8

= 0.318

SNR_{B1} = (0.52 + 5.65 + 9.33 + 12.33 + 8.23 + 7.19 + 8.39 + 8.13)/8= 7.741

(see the bold values in the table **4.9**).

The level for which the product is the maximum is picked as the best setting of the criterion i.

All the products P_{ij} are summarized in the table **4.13**, in which one can deduce the best settings of the criteria. The optimum of Taguchi (e.g. **Opt** in the table **4.12**) is defined by the optimal settings: A = 3, B = 4, C = 4, D = 4, E = 4, F = 4, G = 4, H = 4, & I= 4, with average efficiency E_{Opt} = 0.55, and average loss function SNR_{Opt} = 13.1 decibels.

4.4.3.3. Final 3PL selection

After performing DEA, nine 3PLs are remaining in the competition. Within the orthogonal plan of Taguchi in the table **12**, we compute for each one its quality engineering functions. We report the results in the table **14**, and we see that the optimum of Taguchi presents the maximum of efficiency 0.56, and the maximum robustness 13.16. It is followed by the 3PL7 with efficiency 0.31, and robustness 8.80. The 3PL14 rejected early by DEA method present the lowest values of engineering functions. The final ranking provided by the robust integrated approach is:

$$3PL_7 \succ 3PL_1 \succ 3PL_6 \succ 3PL_4 \succ$$
$$3PL_5 \succ 3PL_8 \succ 3PL_2 \succ 3PL_3 \succ 3PL_9$$

The suggested approach not only classify the candidates according to their efficiency and resilience, but also provide the gap of the selected one relatively to the Optimum of Taguchi. In our case, the winner 3PL7 presents **a gap** of efficiency of 43.6%, and a gap of robustness of 33.2%. This information is very important both for the focal company and the 3PL provider to develop together a continuous improvement plan to catch up the gaps.

Table 4.13

Marginal Efficiency E & Signal Noise Ratio SNR of each criterion level

(j) Level of the criterion *i*		(1)	(2)	(3)	(4)	Max Eij* SNRij	settings of Taguchi Optimum
A	E_{Aj}	-	0.300	0.293	-	0293*8.046 = 2.357	3
	SNR_{Aj}	-	7.554	8.046	-		
B	E_{Bj}	0.318	0.282	0.291	0.295	0.295*8.123 = 3.340	4
	SNR_{Bj}	7.471	7.628	7.979	8.123		
C	E_{Cj}	0.284	0.312	0.288	0.302	0.302*8.059 = 2.432	4
	SNR_{Cj}	7.491	7.784	7.867	8.059		
D	E_{Dj}	0.279	0.311	0.283	0. 313	0.313*8.395 = 2.625	4
	SNR_{Dj}	7.392	7.756	7.656	8.395		
E	E_{Ej}	0.281	0.308	0.293	0.304	0.304*8.106 = 2.468	4
	SNR_{Ej}	7.420	7.691	7.983	8.106		
F	E_{Fj}	0.281	0.313	0.290	0.302	0.302*8.027 = 2.421	4
	SNR_{Fj}	7.430	7.810	7.934	8.027		
G	E_{Gj}	0.248	0.302	0.301	0.335	0.335*9.131 = 3.056	4
	SNR_{Gj}	6.319	7.445	8.306	9.131		
H	E_{Hj}	0.251	0.303	0.305	0.327	0.327*8.397 = 2.749	4
	SNR_{Hj}	6.418	7.462	8.400	8.397		
I	E_{Ij}	0.255	0.306	0.297	0.327	0.327*8.916 = 2.918	4
	SNR_{Ij}	6.564	7.537	8.183	8.916		
J	E_{Jj}	0.266	0.308	0.298	0.313	0.313*8.473 = 2.649	4
	SNR_{Jj}	6.929	7.610	8.188	8.473		

Table 4.14

3PL ranking, and relative performance gaps compared to Taguchi optimum

Alternative	Efficiency E	Robustness SNR	E*SNR	3PL rank	Relative gap to E(Optimum)	Relative gap to SNR(Optimum)
3PL1	0.31	8.66	2.73	2	43.3%	34.2%
3PL2	0.29	7.91	2.26	7	48.5%	39.9%
3PL3	0.28	7.69	2.15	8	49.7%	41.6%
3PL4	0.30	8.31	2.47	4	46.4%	36.9%
3PL5	0.29	8.27	2.44	5	47.0%	37.1%
3PL6	0.31	8.64	2.66	3	44.7%	34.3%
3PL7	0.31	8.80	2.76	1	43.6%	33.2%
3PL8	0.30	8.09	2.42	6	46.1%	38.5%
3PL9	0.22	5.35	1.18	9	60.3%	59.3%
Optimum	0.56	13.16	7.31	*	*	*
3PL14	0.20	4.83	0.96	-	64.1%	63.3%

4.4.4. Discussion

Consider the 3PLs order vectors given by the evaluation methods QFD (*a*); QFD-AHP (*b*); QFD-Fuzzy AHP (*c*); and the DEA-QFD-Fuzzy AHP-Taguchi Robust Design (*d*), in the table **4.15**.

At the first level of analysis, it is clear that QFD is less accurate than QFD-AHP, but the two first ranks of 3PL candidates remain not affected, apparently. However, the QFD-Fuzzy AHP may have an influence on the first rank of the first rank than QFD-AHP. It takes five permutations to jump from the ranking of QFD-Fuzzy AHP to that of our suggested approach. The approach shows a steady position for the first rank, but a sensitive change for the second and the third rank.

At the second level of analysis, rank correlation statistics are useful for determining to which extent there is a correspondence between two measurements, particularly when the measures themselves are of less interest than their relative ordering. We use the Kendall rank correlation (Kendall, 1970) to measure the strength of dependence between the four order vectors (a), (b), (c), and (d).

The following formula is used to calculate the value of Kendall rank τ between (*c*), and (*d*):

$$\tau = \frac{n_C - n_D}{n_C + n_D} \qquad (16)$$

Where:

n_C : The number of Concordant pairs

n_D : The number of Discordant pairs

A concordant pair C is when the rank in the second order vector is greater than the rank in the former variable. Otherwise, the pair is discordant D.

(*c*)									
6									
5	D								
7	C	C							
4	D	C	C						
3	D	C	C	D					
2	D	C	C	C	C				
1	C	C	C	C	C	C			
8	C	D	D	C	C	C	C		
9	C	C	C	C	C	C	C	C	
(*d*)	2	7	8	4	5	3	1	6	9

$$\tau = \frac{29-7}{29+7} = \frac{22}{36} = 0.61$$

The Kendall rank correlation matrix *M* of respectively (*a*), (*b*), (*c*), and (*d*) is:

$$M = \begin{pmatrix} 1 & .92 & .94 & .80 \\ .92 & 1 & .92 & .75 \\ .94 & .92 & 1 & .61 \\ .80 & .75 & .61 & 1 \end{pmatrix}$$

In general, the logistics outsourcing companies are interested not only to the first candidate, but also for the second in order to secure more their service supply, and to create competition between two suppliers. The matrix of Kendall rank correlation shows low correlation coefficients, between QFD-based methods, and the suggested approach. So, using inappropriate evaluation method may mislead the company in its choice of suppliers.

Table 4.15

3PLs' ranking comparison between selection approaches

	Ranking of 3PL candidates								
Ordinary QFD	7	5	6	4	3	1	2	8	9
	6	5	7	4	3	1	2	8	9
+2 permutations = QFD/AHP	5	6	7	4	3	1	2	8	9
	5	6	7	4	3	2	1	8	9
+2 permutations = QFD/Fuzzy AHP	6	5	7	4	3	2	1	8	9
	8	5	7	4	3	2	1	6	9
	8	5	7	4	2	3	1	6	9
	2	5	7	4	8	3	1	6	9
	2	8	7	4	5	3	1	6	9
+5 permutations= QFD/Fuzzy AHP/Taguchi Robust Design	2	7	8	4	5	3	1	6	9

4.5. Conclusion

The integration of 3PL suppliers in the SC is a strategic decision. The focal company within the SC should integrate the outsourcing decision to optimize its SC configuration, to distinguish the outsourced logistics activities from those to perform in-house. Once the optimal level of logistics outsourcing in determined, the question to ask is "How" to select the most efficient 3PL to perform the activities, in the context of sustainable development. To do so;

1) Sustainable criteria, and Risk factors which are inherent to any business activity must be identified, categorized, and leveled, and

2) Develop a decision structure to; a) Consistently, parametrize the decision factors, according to the logistics needs, and to business strategies; and b) Classify the 3PL candidates, according to their efficiencies, in the context of business uncertainties.

The selected 3PL is not the most effective candidate to satisfy the logistics needs, but the most efficient one, which achieves the real logistics needs by tacking into account the resource limitations (e.g. budget of buyer and capacities of 3PL suppliers), and by considering extra resources to mitigate the risk factors. We provide all the factors required to perform the 3PL selection for inbound, outbound, and reverse logistics outsourcing. We suggest a DEA method to shorten the list of candidates after receiving applications of the call for tender. We were inspired from the optimization of products and industrial process, to transfer the Taguchi Robust Design technique to optimize the service processes. So, the logistics activities being outsourced are considered as a process transforming inputs (e.g. resource and capability criteria) to outputs (e.g. performance criteria), and submitted to a set of disturbance factors (e.g. risk factors).

The QFD-Fuzzy AHP method is performed to consistently parametrize the decision factors, and the appropriate Taguchi orthogonal plan leads to determine the Optimum of Taguchi; a virtual most efficient 3PL, with respect to which all the 3PL remaining in the competition are compared to. The selected 3PL should be the closet one to the optimum of Taguchi.

The DEA-QFD/Fuzzy AHP-Taguchi Robust Design provide a consistent, and robust tool fro the problem of supplier selection, in the context of sustainable SC, and we believe that the main contribution of this paper is the integration of one of the most powerful tool of quality engineering in the field of selection problems (e.g. suppliers, equipment…). This approach does not require sophisticated decision supports, but only a commercial software to run DEA programming models, and a shift of Microsoft excel to perform both QFD-Fuzzy AHP, and Taguchi experiments in a suitable orthogonal plan.

The suggested approach still presents some limitations to improve in furthers researches: 1) The selection criteria should be adapted, leveled in suitable settings according to the industry sectors. Our criteria and their settings are inspired from some recent empirical studies; 2) The negative correlations between logistics requirements, between criteria, and between risk factors were no considered in QFD-Fuzzy AHP, and this may consecutively, influence the weights of evaluation; and 3) the most critical drawback is related to the difficulty to measure accurately the efficiency of a service process. The technical efficiency as a rational function of linear combinations remains a preliminary modelling, and needs to be refined in the sense of considering the complex interaction between the factors in the context of sustainable development process.

Table 4.12

Orthogonal Plan of Taguchi: The L32b vs L9 complete parameter design layout

Risk factors							K	r_1	0.37		1	1	1	5	5	5	9	9	9		
							L	r_2	0.11		1	5	9	1	5	9	1	5	9		
							M	r_3	0,13		1	5	9	5	9	1	1	9	5		
							N	r_4	0.39		1	5	9	9	1	5	5	9	1		
Sustainable Criteria											**Efficiency & Loss function of Taguchi**										
Run	A	**B**	C	D	E	F	G	H	I	J	$E_n = \frac{1}{M}\cdot\sum_{k=1}^{M} E_{nk}$										
	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	w_{10}	$SNR_n = -10.\log\left[\frac{1}{M}\cdot\sum_{m=1}^{M}\frac{1}{(E_{nm})^2}\right] + \underbrace{20.\log\sum_{n=1}^{N} E_n}_{\text{Standard factor}}$										
(*n*)	.11	**.09**	.10	.09	.13	.09	.12	.11	.10	.06	Enm									En	*SNRn*
1	7	**9**	9	9	9	9	3	3	3	3	.19	.13	.10	.10	.13	.11	.11	.08	.11	**.12**	**0.52**
2	7	**9**	7	7	7	7	5	5	5	5	.36	.24	.19	.18	.23	.21	.20	.15	.20	**.44**	**5.65**
3	7	**9**	5	5	5	5	7	7	7	7	.59	.38	.28	.28	.36	.32	.30	.22	.30	**.34**	**9.33**
4	7	**9**	3	3	3	3	9	9	9	9	.92	.55	.40	.39	.52	.45	.42	.31	.43	**.49**	**12.33**
5	7	7	9	9	7	7	7	7	9	9	.54	.37	.29	.28	.35	.32	.30	.23	.30	.33	9.36
6	7	7	7	7	9	9	9	9	7	7	.56	.39	.30	.29	.37	.33	.31	.24	.32	.35	9.70
7	7	7	5	5	3	3	3	3	5	5	.37	.23	.16	.16	.21	.19	.17	.13	.18	.20	4.68
8	7	7	3	3	5	5	5	5	3	3	.40	.25	.18	.18	.23	.20	.19	.14	.19	.22	5.40
9	7	5	9	7	5	3	3	5	7	9	.46	.30	.22	.22	.28	.25	.23	.18	.24	.26	7.21
10	7	5	7	9	3	5	5	3	9	7	.49	.32	.23	.23	.30	.27	.25	.19	.25	.28	7.70
11	7	5	5	4	9	7	7	9	1	5	.51	.33	.25	.25	.31	.28	.26	.20	.27	.29	8.16
12	7	5	4	5	7	9	9	7	5	1	.54	.35	.26	.26	.33	.29	.27	.21	.28	.31	8.61
13	7	3	9	7	4	5	7	9	5	1	.55	.35	.26	.26	.33	.29	.28	.21	.28	.31	8.63
14	7	3	7	9	5	4	9	7	1	5	.55	.35	.26	.26	.33	.29	.27	.20	.28	.31	8.54
15	7	3	5	4	7	9	1	5	9	7	.49	.32	.23	.23	.30	.26	.25	.18	.25	.28	7.67
16	7	3	3	5	9	7	5	3	7	9	.47	.31	.23	.22	.29	.25	.24	.18	.24	.27	7.37
17	5	**9**	9	3	9	3	5	7	5	7	.55	.34	.25	.25	.32	.28	.26	.19	.27	**.30**	**8.23**
18	5	**9**	7	5	7	5	3	9	3	9	.45	.30	.22	.22	.28	.25	.23	.18	.24	**.26**	**7.19**
19	5	**9**	5	7	5	7	9	3	9	3	.52	.34	.25	.25	.32	.29	.27	.20	.27	**.30**	**8.39**
20	5	**9**	3	9	3	9	7	5	7	5	.51	.33	.25	.24	.31	.28	.26	.20	.26	**.29**	**8.13**
21	5	7	9	3	7	5	9	3	7	5	.51	.33	.25	.25	.31	.28	.26	.20	.27	.29	8.17
22	5	7	7	5	9	3	7	5	9	3	.52	.34	.25	.25	.32	.28	.27	.20	.27	.30	8.32
23	5	7	5	7	3	9	5	7	3	9	.49	.31	.23	.23	.30	.26	.24	.18	.25	.28	7.61
24	5	7	3	9	5	7	3	9	5	7	.50	.32	.24	.23	.30	.27	.25	.19	.25	.28	7.78
25	5	5	9	5	5	9	5	9	9	5	.58	.38	.28	.28	.36	.32	.30	.23	.30	.34	9.34
26	5	5	7	3	3	7	3	7	7	3	.50	.31	.22	.22	.29	.25	.24	.17	.24	.27	7.30
27	5	5	5	9	9	5	9	5	5	9	.54	.36	.27	.27	.34	.30	.28	.21	.29	.32	8.85
26	5	5	3	7	7	3	7	3	3	7	.46	.29	.21	.20	.27	.24	.22	.16	.22	.25	6.64
29	5	3	9	5	3	7	9	5	3	7	.56	.35	.25	.25	.33	.29	.27	.20	.27	.31	8.46
30	5	3	7	3	5	9	7	3	5	9	.52	.33	.24	.24	.31	.27	.25	.19	.26	.29	7.86
31	5	3	5	9	7	3	5	9	7	3	.51	.34	.25	.25	.32	.28	.26	.20	.27	.30	8.25
32	5	3	3	7	9	5	3	7	9	5	.53	.34	.25	.25	.32	.28	.26	.20	.27	.30	8.20
Opt	**5**	**3**	**3**	**3**	**3**	**3**	**9**	**9**	**9**	**9**	**1.1**	**.63**	**.43**	**.43**	**.58**	**.50**	**.46**	**.33**	**.47**	**.55**	**13.1**
A 1	5	5	7	9	3	5	9	7	3	5	.56	.36	.26	.26	.34	.30	.28	.21	.28	.31	8.66
A 2	5	5	5	5	9	7	5	5	9	5	.49	.32	.24	.24	.30	.27	.25	.19	.26	.29	7.91
A 3	5	5	5	5	7	9	5	5	7	7	.49	.32	.23	.23	.30	.26	.25	.19	.25	.28	7.69
A 4	7	5	7	9	5	7	7	7	5	7	.50	.34	.25	.25	.32	.28	.27	.20	.27	.30	8.31
A 5	7	5	7	9	9	5	7	7	7	5	.49	.33	.25	.25	.31	.28	.26	.20	.27	.29	8.27
A 6	7	3	9	7	9	7	7	7	7	7	.51	.35	.26	.26	.33	.29	.28	.21	.28	.31	8.64
A 7	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**9**	**5**	**7**	**.52**	**.35**	**.27**	**.26**	**.33**	**.30**	**.28**	**.21**	**.29**	**.31**	**8.80**
A 8	5	4	5	5	5	5	5	7	5	5	.56	.34	.24	.24	.32	.28	.26	.19	.26	.30	8.09
A 9	5	5	3	7	3	3	5	3	3	5	.43	.25	.18	.18	.23	.20	.19	.14	.19	.22	5.35
A14	7	5	7	7	7	7	3	5	5	5	.34	.22	.17	.17	.21	.19	.18	.14	.18	.20	4.83

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Chapter 5:

General Conclusion

In "Sustainable" SCs, environmental and social criteria need to be fulfilled by the members to remain within the SCs, while it is expected that competitiveness would be maintained through meeting heterogeneous customer needs, securing supplies, and related economic criteria. The Sustainable SC building goes through the design of a climate change resilient SC design, completed with an effective design for environment of products, and the activation of environmental & social practices between the actors of the global SC. So, to build its Sustainable SC, the Focal Company FC within the SC should integrate its customers, and notably its suppliers in the process of sustainable development. However, the effective integration of suppliers goes through an optimum, out of which adverse implications may affect the performance of the SC. Third Party Logistics service providers (3PLs) as particular suppliers, possess the potentials to activate sustainable practices between different actors of the SC, expect that the FC must determine their optimal level of integration to achieve the expected sustainable performances, and also must select the most efficient one to promote the concepts of sustainable development. The thesis has developed a two-stage stochastic modelling approach to help the FC determining not only the optimal level of 3PL within the climate change resilient SC, but also the optimal plan of Low Carbon Reduction investment for counteracting the uncertain carbon policies. The thesis has developed also a robust integrated approach to select the most efficient 3PL to perform the outsourced logistics, which have been defined strategically by the two-stage stochastic approach.

5.1. Contribution of the thesis

The contribution of this thesis may be enumerated into **ten** points:

1) The high degree of realism, scope, and complexity characterizing the suggested two-stage modelling approach for designing a climate change resilient SC;

2) The suggestion of a first stochastic plan to capture uncertainty of demand, quality & quantity of returned products, and the logistics costs;
3) The suggestion of three constructive models for roughly estimating the freight transportation, warehousing, and reprocessing costs, and their corresponding GHG emissions of in-sourcing & outsourcing;
4) The introduction of the internal carbon price, as a criterion to provide a normative decision concerning the best Pareto optimal green SC configuration, integrating 3PLs, rather than a constructive decision such as multi-criteria analysis;
5) The suggestion of a second stochastic plan to capture the uncertainty of carbon policy, in the context of a voluntary disclosure carbon regime;
6) The consideration of a set of potential Low Carbon Reduction technologies of both Medium and Heavy Duty Vehicles, to construct the second-stage stochastic model;
7) The consideration of the logistics activities being outsourced, as a business process transforming resources & capabilities into capacity & performances
8) The consideration of risks factors in the outsourcing process, in addition to others selection factors.
9) The transfer of Taguchi Robust Design from industrial process optimization to service process optimization
10) The demonstration of the power of the selection approach DEA-QFD/fuzzy AHP/Taguchi Robust Design comparably with the most popular selection methods.

5.2. Limitation of the thesis

We record also ten sensitivities within the suggested approaches, which should be taken back in further researches, as follows:

a) Considering the different issues of SC management, and capturing the uncertainty of some parameters increase significantly the model's size. Thereby the time of data development, is affected so much.

b) Although we use special logistics reviews such as Cap Gemini consulting, American Transportation Research Institute, and European Commission - Mobility and Transport DG – Library, to construct the computing logistics costs models and corresponding GHG emission models, other studies per industry sectors are of great utility to compare real economical, and environmental performances of logistics operations, between private operators and 3PL services providers.

c) Integrating logistics outsourcing decisions in the SC network design increases the model complexity by making quadratic the multi-objective function, thus affects the time of resolution.

d) Solving the model with an algorithm based on Epsilon-constraint approach guarantees the convergence towards Pareto optimal solutions, but the diversity of these solutions closely depends on the desired number of the solutions. Other evolutionary algorithms should be implemented to improve the quality of model solving.

e) The second-stage stochastic model considers only the LCR technologies of freight transportation, but should be extended to other energy efficiencies approaches related to bio-fuel utilization, and related to warehousing & material handling;

f) The stochastic plan of carbon price establishment, in the context of voluntary carbon disclosure regime, remains open to a lot of improvements, because the volatile nature of carbon prices, and the type of industry sector;

g) The operational management of empty back hauls may lead to develop more effective transportation itineraries, and more effective transportation schedules. So, the evolution of heterogeneous fleet size may be subject to serious modifications, which affect the optimality of the second-stage model.

h) The selection criteria should be adapted, leveled in suitable settings according to the industry sectors. Our criteria and their settings are inspired from some recent empirical studies;

i) The negative correlations between logistics requirements, between criteria, and between risk factors were no considered in QFD-Fuzzy AHP, and this may consecutively, influence the weights of evaluation; and

j) the most critical drawback of the selection approach is related to the difficulty to measure accurately the efficiency of a service process. The technical efficiency as a rational function of linear combinations remains a preliminary modelling, and needs to be refined in the sense of considering the complex interaction between the factors in the context of sustainable development process.

5.3. Perspectives

In next few months, we shall address the limitation points c) & d), by focusing on the solving dimension of the suggested two-stage stochastic modelling approach. Within the case study of microwave oven company, the Dynamic Particle Swarm Optimization will be applied as a multi-agent parallel search technique to relocate the global optima of the first stage model (60 nodes, 57 871 decision variables). The convergence & dispersion of optimal SC configurations will be compared to those of the Epsilon constraint method. Relevant managerial insights related the logistics outsourcing & Low Carbon Reduction investment decisions, will be synthesized for building of a climate change resilient SC, in the context of voluntary disclosure Carbone regime.

CIRRELT

Soutenance de thèse de doctorat de

Lhoussaine Ameknassi

«Sustainable Supply Chain Design Integrating Logistics Outsourcing In the Context of Uncertainties»

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This thesis is at the intersection of three research areas: Supply Chain Design; Supply Chain Integration; And Supply Chain Risk Management. It highlights the concepts of Resilience & Sustainability to better understand the challenges of designing Sustainable Supply Chains, their planning, evolution and exploitation. We propose two complementary approaches to construct a sustainable supply chain integrating logistics outsourcing as an efficient flexible strategy; The normative and the prescriptive approaches. The first approach consists of a two-stage stochastic modelling approach to optimize the level of Third-Party Logistics providers' integration, and the Carbon Reduction Investment within a climate change resilient Supply Chain, and during a multi period horizon. The second approach consists of an integrated methodology; DEA/QFD- Fuzzy AHP/Taguchi Robust Design for selecting the most efficient Third-Party Logistics in the context of sustainable & resilient supply chains.

MARDI

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