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SHAHIN GELAREH

Mathematical Modeling and Optimization in Liner Shipping

Laboratoire de Conception, Optimisation et Modèlisation des Systèmes
Ecole Doctorale "Informatique et Information pour la Société"

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I sincerely thank all members of the jury who honored me by accepting examination and evaluation of my work. I am very grateful of Professor Imed Kacem the director of LCOMS, who has offered me the opportunity of achieving this milestone.

In 2007 while working on a Benders decomposition for an Uncapacitated Hub Location Problem, I ended up with serious difficulties in efficiently solving the master problem. Several days I spent on tweaking separation routines, testing different branching tricks, trying to identify some valid inequalities, re-modeling, trial and error, etc. with very minimal progress. I was almost in tears when I stumbled upon an article titled by '*Integer linear models with a polynomial number of variables and constraints for some classical combinatorial optimization problems*' published in *Pesquisa Operacional* in 2003 by Nelson Maculan and his colleagues. That article has literally delivered me my PhD.

I am forever indebted to my dearest colleague, my friend, and my mentor, Professor Nelson Maculan, who took my hand and patiently walked me through the right path and offered me an immense mentorship opportunity since we met first time in Montreal in 2010. I never noticed how has he planned such a smooth transitional period over which he handed me over to a new mentor, Professor Anass Nagih. I am wholeheartedly grateful of Anass Nagih for his generous mentorship and for everything he has done for me by integrating me in his research group and offering me his full support to reach this milestone. We still have a long way to go, together.

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Villeneuve d'Ascq, July 2019 Shahin Gelareh

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Part I

Overview

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Summary of Activities

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1.1 Personal Particulars

Name	**Shahin** GELAREH
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1.2 Employment and Education

◇ **Since September 2012** MAÎTRE DE CONFÉRENCES á l'université d'Artois, Département Réseaux et Télécommunications (R&T), IUT de Béthune, France.

◇ **December 2016 - January 2018** SENIOR LECTURE IN OPERATIONS RESEARCH AND BUSINESS ANALYTICS, Department of Operations and Systems Management, Portsmouth Business School, University of Portsmouth, UK.

◇ **June 2011 - August 2012** POSTDOCTORAL RESEARCHER, Laboratoire LAGIS-CNRS, Polytech'Lille, Université Lille 1, Lille, France

Topic ..... Optimal Traffic Management within Container Terminals with Confined Space in Presence of Intelligent Autonomous Vehicles (IAVs)

Project ..... InTraDE, Interreg IVB, `http://www.intrade-nwe.eu/`

◇ **October 2009 - May 2011** POSTDOCTORAL RESEARCHER, Department of Management Engineering, Technical University of Denmark, Lyngby, Denmark

Topic ..... Energy Efficient Planning in Liner Shipping: Optimization of Global Liner Shipping Operation of MaerskLine.

Project ..... ENERPLAN, Danish Research Council

◇ **May 2008 - October 2009** RESEARCH FELLOW (A), Department of Civil Engineering, National University of Singapore, Singapore

Topic ..... The Impact of Mega-Vessels on the Efficiency of Hub Container Terminals

Project ..... NOL (Neptune Orient Line Fellowship)

◇ **October 2005 - April 2008** DOKTOR DER NATURWISSENSCHAFTEN (DOCTOR RERUM NATURALIUM, DR. RER. NAT.) in Optimization (Mathematics), Department of Mathematics, Technische Universität Kaiserslautern

Place	Department of Optimization, Fraunhofer-Institut für Techno-und Wirtschaftsmathematik (ITWM), Technische Universität Kaiserslautern	
Title	Hub Location Models in Public Transport Planning	
Grade	Magna Cum Laude	
Advisor	Professor Stefan Nickel	
Defence	11 April 2008	
Jury		
First Examiner	Prof. Stefan **Nickel**	Karlsruhe Institute of Technology
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Reporter	Prof. Horst W. **Hamacher**	Technische Universität Kaiserslautern
President	Prof. Willi **Freeden**	Technische Universität Kaiserslautern

1.3 Pedagogic Activities

We first give an overview of the teaching activities based on different disciplines/area and organizations and subsequently elaborate on details of every activity. In the end, we highlight some of the attended workshops and training in the framework of continuous professional development agenda.

1.3.1 Overview

A recapitulate of the teaching activities based on discipline are given in the following. For every programme, the venue, units, type of intervention and involvement as well as the volume of hours are given. Each row in the tables corresponds to one institution. In the remainder, the following abbreviations have been employed: *CM* for *Lecture (Cours Magistral)*, *TD* for *Seminars (Travaux dirigés)* and *TP* for *Labs (Travaux pratiques)*.

1.3.1.1 Computer Science, Networks and Telecommunications (R&T)

	Programme	Units	Type	# Hrs
2012–2016	Full-time, DUT Réseaux et Télécommunications (R&T), IUT de Béthune, Université d'Artois, France	Courses in Networks and Computer Science including, M1207–Bases de la programmation; M2207–Consolidation des bases de la programmation; RCPI01–Programmation orientée objet avancée; M2101–Réseaux locaux et équipements actifs; R1–Concepts généraux des réseaux; R2–Réseaux locaux; R4–Technologie IP; I-C3–Applications client-serveur et Web	CM/TD/TP	> 600h
2011–2012	Part-time, Master in Computer Science, Polytech'Lille, Lille, France	Programmation Structurée	TP	54h

2004–2005	Part-time, B.Sc. degree in Applied Mathematics, Azad University, Iran	Introduction to Programming (Pascal); Data structure in C++	CM/TD/TP	120h

1.3.1.2 Mathematics and Operations Research

	Programme	Units	Type	# Hrs
2017–2018	Full-time, DUT Réseaux et Télécommunications (R&T), IUT de Béthune, Université d'Artois, France	M6. Mathématiques pour le signal discret	CM/TD/TP	48h
2016–2017	Full-time, Undergraduate Programme in Business disciplines, Portsmouth Business School, UK	Courses in quantitative methods for business and accounting	TP/TD	$>$ 140h
2010–2011	Part-time, Doctoral and Master Programmes, Dept. of Management Engineering, Technical University of Denmark, Denmark	Advanced Operations Research	CM/TD/TP	8h
2014–2016	Part-time, Master in Mathematics, Ecole Centrale de Lille, France	Analyse Numérique et Optimisation	TD	$>$ 50h
2004–2005	Part-time, B.Sc. in Economics, Azad University, Iran	Applied Probability and Statistics in Economics; Introduction to Operations Research; Linear and Network Optimization; Operations Research	CM/TD/TP	$>$ 72h
2005–2007	Part-time, Online Content Provider, BrainMass.com, Canada	Online tutor and content provider for on-demand teaching	TD	$>$ 200h

1.3.1.3 Business and Operations Management

	Programme	Units	Type	# Hrs
2017–2018	Full-time, Graduate Programme in Business Disciplines, Portsmouth Business School, UK	Operations Management	CM/TD/TP	48h

2016–2017	Full-time, Undergraduate Programme in Business Disciplines, Portsmouth Business School, UK	Business Innovation Development Project; Enterprise Resource Planning (ERP-SAP); Business Intelligence (BI-SAP); IT skills for Business and Analytics	CM/TD/TP 48h
2004–2005	Part-time, B.Sc. in Business Management, Azad University, Iran	Project Management	CM/TD/TP $>$ 20h

1.3.2 Detailed Pedagogic Activities

In the following, we present our teaching activities by institutions. For every institution, we grouped the teaching activities by pedagogic programmes (bachelor, master or doctoral). Subsequently, we elaborate on every individual unit, its content ad the pedagogic aims and objectives.

1.3.2.1 Teaching and Responsibilities as Senior Lecturer, Portsmouth Business School

a) Undergraduate Programme in Business and Management:

1) **Quantitative Methods for Business** Upgrade and redesign of the content for a first-year common unit at the undergraduate level in business disciplines has been carried out. The objective of this unit is to provide students (given their very diverse and heterogeneous backgrounds) with basic skills in quantitative methods and tools (Microsoft Excel and scientific calculators) required for the other subsequent units of this programme. This unit starts with reviewing basics of statistics, random variable (qualitative, quantitative, ordinal, nominal etc.), descriptive statistics (measures of location and dispersion), correlation and regression, probability distribution functions such as binomial, normal, poisson, confidence intervals, test and hypotheses ends with basics of optimization modeling using linear programming and solution (only the graphical approach). The use of calculator and MS Excel is emphasized in lectures (CM), seminars (TD) and lab sessions (TP). This unit is delivered through sessions of lecture (CM, 12 hours), seminar sessions (TD, 6 hours) and lab sessions (TP, 6 hours), two self-assessments via online tests and one final written exam. Moreover, 20% of evaluation in this unit comes from another unit (see below)

2) **Business Innovation Development Project** This unit is the 6-th unit in this undergraduate business degree, which contributes 20% to every other unit in this degree. The objective of this unit is to provide the first-year students with the opportunity to employ the knowledge they are acquiring in the other five units in a group project of an innovative business idea of their own choice. Through a series of inventories and self-assessment, students inform themselves their personal Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis, and achieve a more objective reflective understanding of themselves, achieve an understanding of diversity and its importance, gender balance, social and corporate responsibility (citizenship), task sharing and time management, etc.

   They then form groups of 4-5, allocate the tasks, sign an agreement of task allocation, develop an idea, carry out the market research and analysis (wit respect

to the contents of different units, namely, economics, quantitative methods, accounting, marketing and operations management) and present their work in front of a jury comprised of academics and professionals from industry and defend it for 10 minutes. This unit runs over the entire first year (24 weeks) through a series of lectures (including those delivered by the invited speakers among the successful individuals) and a series of workshops (TP) students are supervised (feed-forward) and provided with constructive feedback to develop their skills and carry out the projects.

3) **Enterprise Resource Planning Systems** This unit is intended to offer students opportunities to gain experience in advanced spreadsheet modeling of business resource allocations using Microsoft Excel, using programs that help managers make decisions, culminating in the creation of a 'Business Planning Tool' that will help to create one portfolio of work. Students also engage with a live corporate-level Enterprise Resource Planning (ERP) system, SAP S/4HANA. They undertake a number of case studies that demonstrate the power of ERP software, which treats an organisation as a collection of integrated business processes, and less as a collection of functional departments. Students also gain an appreciation of the increased employability prospects afforded by having ERP understanding compared with those open to graduates without that exposure.

   The aims of this units are the following: 1) To develop an appreciation of the link between accounting and IT systems used to assist managerial decision-making, and to develop skills in using spreadsheet and ERP applications, 2) To develop an integrative view of IT systems, business processes and ERP system module functionality related to relevant functional areas, and an awareness of ERP system solutions on the market, 3) To develop an understanding of the benefits and challenges of implementing ERP systems, which involve sales, production planning, financial and cost accounting, and HR functions, and 4) To provide opportunities to use a live ERP system to test a range of business processes in SAP Next-Gen computer labs.

   This unit is comprise of, 1) Introduction to Microsoft Excel, tables, ranges and databases, data integrity, subtotals, validation and security, 2) Advanced functions, names and formula auditing tools, pivot tables, data models, slicer and '*what if*' analyses, 3) formatting workbooks, charts, macros, VBA, MS Excel file formats, Arrays, forms and applications, 4) Linking/embedding workbooks, importing database data, saving MS Excel files to Dropbox and Google Drive, 5) Building a '*Business Planning Tool*' application using advanced features of Microsoft Office, 6) Factors influencing the optimal choice of IT hardware and software systems for companies of all sizes, 7) Best practice in planning, scoping, designing, implementing and managing change in an ERP project, 8) The SAP ERP ecosystem, on-premise, hosted and cloud-based ERP options, 9) Introduction to SAP Leonardo, SAP HANA, SAP Financials, SAP BI (SAP BW/BusinessObjects), the Internet of Things, Machine Learning, Blockchain, AI etc., and 10) SAP Case Study Analysis of Global Bike Incorporated using SAP ERP software modules: Sales and Distribution (SD), Materials Management, *i.e.* Purchasing, Production Planning (PP), Financial Accounting (FI), Controlling *i.e.* Management Accounting (CO), and Human Capital Management (HCM).

   This unit is delivered in 48 hours: 18 hours lectures (CM), 18 hours seminars (TD) and 12 hours lab sessions (TP).

4) **Business Intelligence** The objective of this unit is to investigate how information systems and other computer based software tools can support management decision making. As well as examining the traditional management information

system, the unit explores some of the more contemporary and innovative types of information systems, which management in many organisations are now using. The unit blends together aspects of computer science, management science, behavioural science and business management.

The aim of this unit is to develop competency and capabilities in the students to: 1) Critically explain how a range of BI technologies and process work and how organisations may apply them, 2) Defend a report and/or visual presentation that investigates a BI issue in depth, and 3) Apply BI theory using practical BI software.

This unit covers the following contents: 1) Introduction to BI, overview of BI, evolution of computerised decision aids, BI versus MIS, management and management needs, 2) Decision making, modeling and Decision Support System (DSS): modeling theory, process certainty, uncertainty and risk, 3) BI and data warehousing: DBMS vs. DW, data marts meta data, 4) Business analytics and data mining, mining techniques and OLAP technology, 5) Artificial Neural Networks (ANN) for data mining, basic concepts, learning in ANN, ANN applications, 6) Business performance management, BPM and BI, Six Sigma, BPM architecture and performance dashboards, 7) Collaborative computing, nature of group meetings, aims of GDSS and requirements, 8) Interactive visualisation, SAP Crystal Dashboard and SAP Lumira, 9) Intelligent Systems over the Internet, intelligent agents, classification and types of agents, intelligent agents and e-commerce, 10) MSS development, traditional SDLC and MSS prototyping team-developed versus end-user developed.

This unit is delivered in 48 hours: 24 hours lectures (CM) and 24 hours labs (TP).

b) **Postgraduate Programme in Business and Management:** The involvement includes two master-level programmes. A particularity of this programme is the higher number of international students for which the diversity in background and provision of support for their engagement in the unit must be even further taken into account.

1) **Master of Business Management:** Amendments and redesign of the content and support of unit in seminars for an Operations Management unit in master level has been carried out. This programme, similar to many other master degrees in management, has an audience with very diverse backgrounds. This ranges from qualitative to very quantitative, from sports' science education to computer engineering and electrical engineering. The objective of this unit is to educate students and familiarize them with essential elements of managing a business (such as resources and transformation, supply chain design, location, scheduling, information, flow etc.).

In particular, this course includes, transformation process and performance measures, design of processes, products and services, foundation of information systems and examples, the future of information systems, facility location, supply chain, inventory management, quality and sustainable operation. This unit is comprised of CM (12 hours), TD (12 hours) and assessment is based on two essays (critical review of a recent article in the lierature related to the content of unit and developing a case study) and one final exam (multiple choice) covering the whole content.

2) **Master of Supply Chain Management and Logistics:** Design and develop of a new unit '*Business Analytics and IT Skills for Consultancy*', which aims to develop basic skills in students by helping them gain an appreciation of different techniques (data modeling, cleansing, mining, processing, visualizing and interpreting), tools (such as Knime, Python, Microsoft BI etc.) and some real case studies enabling them to analyze complex situations, extract knowledge from data and provide insights for decision makers.

   Here, we are dealing with a group of 50-60 students with tremendously diverse academic backgrounds, some of whom are very skilled in quantitative methods, which others may not be comfortable with. The objective of this unit is to help students gain appreciation of concepts, techniques and tools necessary to analyze a business. The approach adopted for delivering this unit relies on a variation of '*inverse pedagogy*' in which we start from some case studies, move backward towards the theoretical concepts. This unit is comprised of CM (12 hours) and TP (12 hours) and the evaluation is based on two self-assessments via online tests and a final project.

1.3.2.2 Teaching and Responsibilities as Maître de Conférences, IUT de Béthune, Université d'Artois, France

The PPN (programme pedagogique nationale) governs and sets the general framework and contents of the units for a DUT (Diplôme Universitaire Technologies) at IUTs (Institute Universitaire de Technologie) —the essential ones as well as the complementary ones for every degree.

The principal objective in these degrees is to prepare students and provide them with short-term practical contents —strongly supported by lab sessions— followed by an internship in industry for a quick insertion in the job market. However, optional units are foreseen for those who aim to pursue an engineering degree in an engineering school.

During 2012-2013 (under the rule and mandate of pre-2013 PPN), the following standard units have been supported in labs (TP) and seminars (TD): a) Concepts généraux des réseaux (R1); b) Réseaux locaux (R2); c) Technologie IP (R4); d) Applications client-serveur et Web (I-C3), and e) Bureautique et les outils informatique.

However, since 2013, under the new PPN, unit coordination (CM/TP/TD) for the following units has been assumed:

a) **Réseaux locaux et équipements actifs (M2101 replacement for R1/R2):** The objective of this unit is to develop an appreciation in the students of local networks based on the Ethernet technology and to configure the local network hardware. By the end of this unit, the students are expected to have developed the following competencies: installation, troubleshooting and verification of cabling, install and configuration of active hardware and deploy, maintain and troubleshoot the network structure based on physical connection technology.

   The contents delivered include: pre-cabling of building and network cabling, different topologies (physical and logical), Ethernet norms 802 (802.1, 802.2, 802.3), Ethernet communications (MAC address learning, dissemination and broadcasting), different hardware (repeater, bridge, switch, router etc.), configuration of a segmented network single VLAN (multi-VLAN, Inter-VLAN routing, sub-interface, etc), redundancy

(STP, RSTP, etc.) and configuration of a router as a local network gateway.

During the lab sessions, students become familiar with the techniques of analysing Ethernet frames in relation to different protocols using softwares such as WireShark and PacketTracer.

b) **Bases de la programmation (M1207):** The objectives of this unit is to homogenize the skills and competencies students have obtained at the high school (BAC) and enabling them to propose software solution for a list of simple tasks. It is expected that by the end of this lecture, students achieve the skills for designing algorithm based on a list of simple tasks, translate the algorithm in a structured programming language, compile, debug and test a program. This course is expected to be delivered in a project-based pedagogy and with a very light flavor of paradigm of objects. This unit is a first year unit composed of 30 hours of direct contact (*i.e.* CM:6 hrs, TD:6 hrs and TP:18 hrs)).

c) **Consolidation des bases de la programmation (M2207):** The objective is that students become capable of proposing an object oriented software solution to carry out a task. By the end of this unit, students are expected to achieve competency for designing an application taking into account the concept of objects and the relationship among them as well as developing a simple client-server application in an object oriented programming language. M1207 serves as the pre-requisite for this unit and both follow a project-based pedagogy. The contents of this unit include: principles of object oriented programming, basics of inheritance, error handling mechanisms, client-server architectures, developing a single-client/server service as well as a query-based client/server service. This is a first year unit composed of 30 hours of direct contact (*i.e.* CM:6 hrs, TD:6 hrs and TP:18 hrs).

d) **Mathématiques pour le signal discret (M4210C):** This unit is a second year complementary unit for those students aiming at pursuing an engineering degree. The objective in this unit is to enable students to use Z-transform and become familiar with the notion of convergence in series. By the end of this unit, the students are expected to be capable of determining the convergence domain of power series or that of a Z-transformed, power series development, using the formula for calculating the Z-transform, the inverses and solving differential equations.

   The content delivered covers definition of sequences, geometric sequences, series, power series (convergence radius, derivation, integration, and development of known power series), Z-transformation, discrete convolution and application to differential equations. This unit is delivered within 30 hours (*i.e.* CM:10 hrs, TD:15 hrs and TP: 5 hrs).

e) **Programmation orientée objet avancée (RCPI01):** The aims and objectives of this unit is to familiarize students with more advanced concepts in object oriented programming. This includes a more in-depth understanding of the notion of inheritance, abstract classes, interfaces and graphical user interfaces. This course is delivered within 18 hours of contact (*i.e.* CM: 6 hrs and TP:12 hrs). M2207 serves as the pre-requisite for this unit and both follow the project-based pedagogy.

The audience is typically composed of a cohort of mostly international students with slightly diverse backgrounds. However, majority of them have followed an education system akin to the local (French) system (including some francophone African countries) making them comparable with home student backgrounds. The major imbalance among them concerns the access and familiarity with the IT technologies.

In March 2013, building on top of my practical experiences in computer networks, I have attended the Cisco CCNA (1& 2) training at the IUT de Pau in Mont-de-Marsan, France and received qualifications as a Cisco instructor for CCNA programme. This has helped me to shape and organize my practical and professional experiences to support my teaching in DUT of Réseaux et Télécommunications.

Relying on that, the content of M2101 (Réseaux locaux et équipements actifs) has been developed and delivered in such a way that while PPN is being respected, both competency and capability in the students are developed in such a way that the CCNA certificate become very achievable for them. This has been achieved using the tools (such as PacketTracer) and being inspired by the Cisco lab roadmap to develop content for M2101.

Given that M2207 and RCPI01 both rely on an object oriented context, the choice of Java (which is an object oriented programming language) in the pre-requisite unit M1207 has proven to be judicious. This choice has been motivated by the exigency of Java with respect to the syntax, structure, data types and coverage of classical concepts of programming in this language. Later, a transition from M1207 to the subsequent units M2207 and RCPI01 proved to be smooth and with significantly less turbulence.

1.3.2.3 Teaching and Responsibilities as Postdoctoral Researcher, Polytech'Lille, France

Programmation Structurée is a unit taught at the master level in computer science at Polytech'Lille (IMA3). While it does not touch the object oriented context, it emphasizes on intensifying the knowledge and understanding of structural programming using C/C++ language. About 54 hours of lab sessions (TPs) have been covered in this unit.

1.3.2.4 Teaching and Responsibilities as Postdoctoral Researcher, Department of Management Engineering, Technical University of Denmark

Advanced Operations Research was designed as an advance master and PhD level course at the Technical University of Denmark. This unit mainly deals with applied side of operations research including modeling large scale real life problems and solution techniques that can be used to address those problems. A total of 8 hours of lectures (CM) have been devoted to: 1) the concept of 'Facility Location' and 'Hub Location Problems' for applications in liner shipping and supply chain network design (4 hours) and, 2) exploiting decomposable structure of resulting models using decomposition techniques —mainly Benders decomposition and Lagrangian methods (4 hours) .

1.3.2.5 Teaching and Responsibilities as Part-time Lecturer, Azad University, Iran

a) **Undergraduate Programme in Business and Management:** Two units have been developed and animated (CM/TP/TD) for this programme: 1) Applied Probability and Statistics in Economics, 2) Introduction to Operations Research.

   The first unit covered almost the same content as in 1.3.2.1 (a.1) with similar aims and objectives.
   The second unit dealt with basics of linear programming, modeling various problems with continuous variable, graphical solutions, transportation and assignment problems and some solution algorithms (*e.g.* Hungarian method etc.), basics of simplex method, degeneracy, modeling using binary and integer variables and the use of software (*e.g.* Lingo and Xpress).

The objective of latter was to enable students understand different modeling techniques, the issues that can occur in a simplex method, analyze and interpret the outcomes reported by the software and packages rather than developing mathematical models. By the end of this unit, the students are able to interpret mathematical models, model simple problems with continuous variables, find optimal solutions graphically and interpret the results and report managerial insights.

The unit is delivered within 45 hours (*i.e.* CM: 20 hrs, TD: 15 hrs and TP: 10 hrs).

b) **Undergraduate Programme in Applied Mathematics:** Two units have been developed and animated (CM/TP/TD) for this programme: 1) Operations Research, 2) Linear and Network Optimization.

The first unit was a sophisticated unit covering linear programming and integer programming, the simplex method (Big-M method, classical simplex and revised version, tableau and graphical approaches), sensitivity analysis in simplex method, related issues in simplex (cycling and degeneracy), project control and relationship with integer programming, assignment and transportation problems and the well-known algorithms (Hungarian method etc.), queuing theory (M/M/1, M/M/1/K, M/M/c/K, Erlang model, arrival and waiting time as well as analytical development) and its applications in discrete-event simulation, stochastic processes and stochastic programming.

The objective was to familiarize students with key concepts in operations research with a moderate level of the underlying mathematics. By the end of this unit, the students should be capable of modeling different phenomena/processes using the key concepts in OR. They become familiar with a set of optimization and simulation packages for every key concept. The unit is delivered within 45 hours (*i.e.* CM:20 hrs, TD: 15 hrs and TP: 10 hrs).

The second unit, dealt with polyhedral description of simplex, revised simplex, degeneracy, sensitivity analysis, network optimization and network algorithms, binary mixed integer programming, polyhedral properties, valid inequalities, face and facets, branch-and-bound method, branch-and-cut, different cutting planes, continuous relaxations, lagrangian relaxation, Benders and Dantzig-Wolfe decompositions, general mixed integer programming, integrality property, etc. The unit is also delivered within 45 hours (*i.e.* CM:20 hrs, TD: 15 hrs and TP: 10 hrs).

c) **Undergraduate Programme in Economics:** The unit involves basic study to acquire a general and mainly qualitative (with a very slight quantitative flavor) aspects of Project Management. This include defining projects and management of projects, 'Projectisation', the 'Iron Triangle' and its limitations, projects and the relationship with programmes, portfolios, project strategy, stakeholder management and selection, basic scheduling techniques, networks, critical path analysis, resource allocation/management, crashing, costing, cost estimation and control, theories of professionalism, the status of the occupation, motivation and leadership of project teams, procurement and commercial management in project context, life-cycle management and change control. The unit is delivered within 45 hours (*i.e.* CM:20 hrs, TD: 15 hrs and TP: 10 hrs).

1.3.2.6 Pedagogic Activities as Online Content Developer and Tutor, BrainMass

BrainMass (https://BrainMass.com) is an online corporation headquartered in Canada that offers tutoring, homework help and solution library services, across all subjects, to individuals learners of all ages at the university, college and high school levels. BrianMass operated

based on problem solving tasks and provides tutorial for specific problems submitted by the learners.

Briefly speaking, the learner seeks help to answer his/her question while the tutor has a very minimal understanding of the leaner's level and background in the course. Therefore, the tutor must prepare the content in such a way that it suits a wide spectra wherein the learner's background lies. Furthermore, such contents are added to a library and will be used if other leaners with similar or different backgrounds would require the same/similar contents.

During 2005-2007, I have collaborated with BrainMass in providing on-demand online contents, developing student-centered material and rich online tutorials. This was a unique experience, which helped me to redefine my teaching style and broaden my view of learning and enrich my course delivery competencies and capabilities.

1.3.3 Continuous Professional Development Activities

Opportunities have been sought and efforts have been made to continuously improve the quality of content preparation, delivery, managing classroom, dealing with absenteeism, dealing with engagement of students in the courses and assessment strategies. Particular focus has been devoted to the following contexts: 1) student-centered learning and taking into account diversity, 2) leaning-by-projects and inverse pedagogy, 3) adopting the successful methods of teaching such as *participative* and *action-based* methods, and 4) different learning philosophies such as *heutagogy*, which concerns autonomy in learning for developing capability and competencies at the same time.

Offering equal opportunity and formative assessment are two key components of my exercised pedagogic activities.

On a regular basis, professional training have been received aiming at maintaining a quality level teaching and improving student experience. Some of these attended training are listed here.

1. Learning by Problem (*l'Apprentissage Par Problème (APP)*),
2. Tools for Dealing with Difficult Situation of Our Students (*Des outils pour gérer les situations problématiques avec nos étudiants*),
3. Inverse Pedagogy (*La pédagogie inversée*),
4. Innovative Practices and Active Methods (*Pratiques innovantes et méthodes actives*),
5. Formative Assessment and 'Response Box' (*Evaluations formatives et boitiers cliqueurs*),
6. How Better Evaluate the Learning of My Students (*Comment mieux évaluer les apprentissages de mes étudiants ?*),
7. Teaching and Posture (*Enseignement et posture*),
8. *Planning Your Teaching to Make a Difference*,
9. *Effective Presentation*,
10. *Enhancing Engagement in Lectures*,
11. *Being a Personal Tutor*,

12. *Developing your Classroom Presence*,
13. *Engaging with International Students*,
14. *Best Practice in the Selection and Admission of Postgraduate Research Students*,
15. *Guidance for Internal/External Examiners and the University Process*,
16. *Effective Time Management*,
17. *Introductory Workshop for Research Supervisors*.

In addition, the following further specific training have been also received in relation to both teaching and research activities.

1. Accompanying and Supervising PhD Students (*Accompagner et Encadrer des Doctorants*), Université Lille 2,
2. *Cisco Certified Network Associate (CCNA 1 and 2)*.

1.4 Research Activities

In this section, we highlight the key components of the research activities so far.

1.4.1 The General Context

The general context of our research centers around *combinatorial optimization* in logistic systems. The optimization of processes across a supply chain heavily relies on modeling them using mathematical programming techniques and taking into account a reasonable level of abstraction. These models are composed of variables representing decisions, one (or more) objective function (time, profit, cost etc.) to be optimized and a set of domain-specific and application-specific constraints to be respected (constraints on resources such as budget, time or feasibility of operations with respect to the existing infrastructures etc.). Subsequently, very efficient algorithms are designed to solve these mathematical models (and also help validate the models on different datasets).

In combinatorial optimization, a *feasible* solution to such a mathematical representation of the problem is constructed by combinations of possible values (from domain) for every decision variable such that all together respect the set of aforementioned constraints. The *optimal* solution, is the feasible solution with the best *objective value*. This set of feasible solution becomes very prohibitive even for very small size problems. As an exhaustive enumeration become unfeasible, special methods of clever enumeration (*e.g.* branch-and-bound-based methods) have emerged to solve such problems in their general form using blackbox solvers.

In practice, a trade-off is achieved between the level of realistic features we can accommodate within a mathematical model and the computational intractability and the state-of-the-arts of the hardware available to carry out computational experiments on those models.

On the other hand, often such problems and the resulting models posses inherent structures that can be investigated and exploited to propose much more efficient methods. Some of such methods are based on decomposing the models into smaller ones that when solved separately in an iterative flow, will produce optimal solution to the complete problem.

The second side (and probably the main scaffold) of our work concentrates on investigating the inherent structures, identify the decomposable sub-structures and propose decomposition algorithms capable of providing optimal solutions (or solution with known deviation from optimality) very efficiently and in a timely manner. To do this, we may also benefit from heuristic techniques that generate feasible solutions without even knowing their quality. In brief, we also wish to push the frontiers of computational efficiency for specific problems in logistics.

The keywords in our research work are *liner shipping*, *network design*, *mixed integer programming* and *decomposition techniques*.

The research work reported int his manuscript is divided into three principal contexts with the corresponding outputs:

1. **Network Design and Maritime Shipping**
   - A completed PhD thesis (N. Belayachi) and one ongoing,
   - Six peer-reviewed ABS[1]-ranked international journal articles ([Monemi and Gelareh, 2017a], [Gelareh et al., 2017a], [Gelareh et al., 2013d], [Gelareh et al., 2013a], [Gelareh and Pisinger, 2011a], [Gelareh et al., 2010], [Gelareh and Meng, 2017] and joint works with the PhD students. [Belayachi et al., 2018], [Wang et al., 2009],
   - Several peer-review international conference papers both jointly with the students and with other fellow colleagues ([Gelareh et al., 2017b], [Gelareh et al., 2015a], [Danach et al., 2015c], [Gelareh and Monemi, 2017], [Gelareh and Meng, 2009], [Semet and Gelareh, 2015]), [Yachba et al., 2014], [Gelareh, 2008a], [Monemi and Gelareh,], [Danach et al., 2016], [Belayachi et al., 2015], [Gelareh et al., 2016b], [Danach et al., 2015a], [Gelareh et al., 2015c], [Danach et al., 2014a], [Gelareh et al., 2014], [Gelareh et al., 2011], [Gelareh, 2010], [Gelareh and Pisinger, 2010a] and [Gelareh and Pisinger, 2010b].
2. **Port Operations**:
   - One completed PhD thesis (K. Yachba, in co-supervision with the University of Oran 1, Algeria),
   - A peer reviewd ABS-ranked journal article ([Gelareh et al., 2013b]) plus a couple of peer-reviewed conference papers jointly with the students ([Yachba et al., 2016], [Yachba et al., 2015]) and a few others with fellow colleagues ([Monemi et al., 2009], [Riera-Ledesma and Gelareh, 2014], [Gelareh, 2013] and [Gelareh et al., 2012]).
3. **Logistics in General**
   - One completed thesis (K. Danach) and one ongoing (O. Kemmar)
   - Crossdocking: An ABS-ranked peer-reviewed international journal article ([Gelareh et al., 2015d]) and a conference papers ([Gelareh et al., 2013c]),
   - Telecommunications: A peer-reviewed ABS-ranked international journal article ([Monemi and Gelareh, 2017c]) and a few peer-reviewed conference papers ([Monemi and Gelareh, 2017b], [Monemi and Gelareh, 2017d] and [Gelareh et al., 2016a]),
   - Petroleum Logistics: A peer-reviewed ABS-ranked international journal article with the PhD student ([Monemi et al., 2015]) and peer-reviewed conference papers jointly with the student and fellow colleagues ([Gelareh et al., 2015b], [Monemi et al., 2016] and [Danach et al., 2014c]).

[1] Association of Business Schools

The following table summarizes the outputs.

Outputs	Quantity
Peer-reviewed journals	19
Peer-reviewed international conferences	24
Peer-review national conferences	23
Under review	3
Book/Monograph	1 (PhD thesis as a monograph [Gelareh, 2008b])
Technical reports	9
Software	1 (BENMIP– An automated Benders Decomposition, PGMO)
PhD students	3 completed and 2 ongoing
Funded projects	More than 6 national, international and European funding

1.5 Supervision

1.5.1 PhD Supervision

In total 3 PhD dissertations have been supervised and successfully graduated since 2008 (please find the co-supervision certificates in the enclosed dossier).

Year	Name	Thesis title	Supervision
01/10/2012–21/02/2018	N. Belayachi	Empty Container Repositioning and Models of Reverse Logistics	K. Bouamrane (50%) & S. Gelareh (50%)
01/10/2012–27/04/2017	K. Yachba	Optimization of Container Stacking in Container Terminals	K. Bouamrane (50%) & S. Gelareh (50%)
09/09/2013–21/12/2016	K. Danach	Hyperheuristics in Logistics	F. Semet (50%) & S. Gelareh (50%)

K. Danach has worked on the methodology of hyper-heuristic and in a more general sense using the paradigm and techniques of Q-learning to exploit the power of a portfolio of low-level heuristics in finding high quality solutions to the combinatorial optimizations

arising in logistics. K. Danach is currently an Assistant Professor and Coordinator of MIS and Management Departments at the Islamic University of Lebanon.

This PhD dissertation has resulted in two journal articles [Danach et al., 2019] and [Monemi et al., 2015] and several conference papers including [Danach et al., 2014a], [Danach et al., 2014c], [Danach et al., 2014b], [Danach et al., 2015c], [Danach et al., 2015b], [Gelareh et al., 2019b], [Gelareh et al., 2017b], [Gelareh et al., 2015b], [Gelareh et al., 2015a], [Monemi et al., 2016], [Danach et al., 2016], [Danach et al., 2015a] and [Gelareh et al., 2015b].

K. Yachba has worked on the optimization of container stacking operations in container terminals using techniques of multi-criteria decision making and multi-agent modeling. She is currently a Mâitre de Conférences at the Relizane University Center in Algeria.

This dissertation has resulted in one journal publication [Yachba et al., 2016] and a couple of conference papers [Yachba et al., 2015] and [Yachba et al., 2014].

N. Belayachi, in her thesis, has worked on the design of liner shipping network with focus on repositioning of empty container resulted by the trade imbalance between east-bound and west-bound trade. Her work relies on mathematical modeling of problem and also metaheuristic methods for solving instances of problem. She is currently a Mâitre de Conférences at the University of Oran1 Ahmed Ben Bella, Algeria.

This dissertation has resulted in one journal publication [Belayachi et al., 2018] and a conference papers [Belayachi et al., 2015].

1.5.2 Supervision of Bachelor and Master Theses

I have supervised a wide range of topics in *Mathematics*, *Operations Research/Management* and *Computer Science/Network and Telecommunications* at the université d'Artois and elsewhere.

Computer Science, Mathematics and Operations Research

I supervised the following internships ('stage') and master dissertations at the université d'Artois.

Year	Name	Dissertation title
2013	K. Keita	Hub Location models with M/M/1 queues: a Benders decomposition approach
2013	J. Luo	Assignment problems in crossdocks

Business and Operations Management

At the graduate level in Business and Management, the following dissertations have been supervised at the Portsmouth Business School.

Year	Name	Dissertation title

Mar 2017– Sep 2017	Y. Liu	Investigating Project Management Success for Project-Oriented Business Organisations from the Perspective of Technical Capacity, Organisation Structure and Leadership
Mar 2017– Sep 2017	Z. Shan	Investigation of an Application of Soft Systems Methodology for Project Management of Construction Industry
Mar 2017– Sep 2017	Y. Wu	Should British Government Authorize Hinkley Point C Project in the Prospective of Project Management?
Mar 2017– Sep 2017	M. Ahmed	Measuring The Effectiveness of an agile Methodology in Approaching the Problem of Uncertainty of Unplanned Maintenance During Commercial Aircrafts' Heavy Maintenance: A Case Study
Mar 2017– Sep 2017	C. Reyes-Jaquez	How Can Lean Thinking Improve the Execution Efficiency in the Process of Paying the Retirement Plan to the Professors in the National Institute of Magisterial Welfare (INABIMA) in the Dominican Republic
Mar 2017– Sep 2017	J. P. Lopez	Economic and Social Benefits that can be Obtained by a Combination of Technology, Project Management and Agile Methodology in the Dominican Republic: Banking and Government Approach
Mar 2017– Sep 2017	S. G. Lopez	Analyzing the Lack of Application Tools that Increase Productivity in the Construction Industry of the Dominican Republic
Mar 2017– Sep 2017	E. Ataro	Analysis of the Most Influential Critical Success Factors in Large Spacecraft and Military Industry
Mar 2017– Sep 2017	S. Dixon	The Use of the Theory of Constraints to Help Plan and Manage Projects More Efficiently

Supervision at the undergraduate level At the undergraduate level (*i.e.* BA (Hons) Business & Management), I have supervised the following dissertations.

Year	Name	Dissertation title
Sep 2017– Mar 2018	J. Tibbert	Service Rate vs. On Shelf Availability: What should be a companies main supply chain KPI?
Sep 2017– Mar 2018	T. Clegg	A Comparison Between the Success of Companies who Operate Online and Companies who Operate Offline Based on Social and Economic Factors.

Sep 2017 - Mar 2018	J. A. Tavendale	A Study to Determine the Impact of Globalization on UK Businesses Operating on both a Local and Global Level
Sep 2017 - Mar 2018	J. Cossins	Supply Chain Management and Bottleneck Correlation

1.5.3 International Collaboration

- **N. Maculan, Professor**, COPPE, Federal University of Rio de Janeiro, Brazil: collaboration in the framework of a few research projects:
  1. *A Coopetitive Framework for Hub Location Problems in Transportation Networks* (see, [Gelareh et al., 2017a]),
  2. *Heuristic Methods for Single String Planning Problem Arising in Liner Shipping Industries* (see, [Gelareh et al., 2013d] and [Gelareh et al., 2011]),
  3. *Hub-and-spoke network design and fleet deployment for string planning of liner shipping* (see, [Gelareh et al., 2013a]).
- **D. Jones, Professor**, University of Portsmouth, UK: collaboration in the framework of a research project: *Bi-objective Load Balancing Multiple Allocation Hub Location: A Compromise Programming Approach* (see, [Monemi et al.,]).
- **D. Pisinger, Professor**, Technical university of Denmark: collaboration in the framework of the research project ENERPLAN:
  1. *Heuristic Methods for Single String Planning Problem Arising in Liner Shipping Industries* (see [Gelareh et al., 2013d] and [Gelareh et al., 2011]),
  2. *Fleet Deployment, Network Design and Hub Location of Liner Shipping* (see, [Gelareh and Pisinger, 2011a], [Gelareh and Pisinger, 2010a] and [Gelareh and Pisinger, 2010b]),
  3. Liner Shipping Hub Network Design in a Competitive Environment (see, [Gelareh et al., 2010]).
- **K. Bouamrane, Professor**, Université d'Oran 1, Oran, Algeria: a wide range of collaboration in the framework of bilateral projects, co-supervisions and academic exchanges:
  1. A Franco-Algerian PHC-Tassili project on *Optimization in Maritime Transport: Port Operations at the Quay Side and Empty Repositioning on the Seaside*,
  2. PhD co-supervision:
     - *Vers une contribution dans la logistique inverse pour repositionnement des conteneur vide*, N. Belayachi, 2013–2018,
     - *Vers une contribution dans le transport maritime de marchandises: optimisation de placement des conteneurs dans un port maritime*, K. Yachba, 2013–2017,
     - *Fleet deployment in LNG shipping industry: A case study of Algerian Hyproc shipping company*, I. Boukerche, 2015–2019,
     - *Integration of hyper-heuristics and exact methods for optimization in logistics*, O. Kemmar, 2016–2019.
  3. Joint publications:

  - *Conference publications* [Yachba et al., 2014], [Yachba et al., 2015] and [Belayachi et al., 2015],
  - *Journal publications* [Yachba et al., 2016] and [Belayachi et al., 2018].

- **Q. Meng, Assoc. Professor**, National University of Singapore, Singapore: Collaboration in the framework of a research project: *Impact Analysis of Mega-Vessels on the Efficiency of Hub Container Terminals*.

  1. Joint publications:
     - *Journal publications* [Gelareh and Meng, 2017].
     - *Conference publications*, [Monemi et al., 2009], [Wang et al., 2009] and [Gelareh and Meng, 2009]
  2. PhD co-supervision:
     - *Liner ship fleet planning with uncertain container shipment demand*, T. Wang, 2007–2011, resulted in a joint publication [Wang et al., 2009]

- **R. N. Monemi, Research Fellow**, Southampton Business School, UK: Collaboration in different aspects and several projects:

  1. *BENMIP: A generic Benders Decomposition for Mixed Integer Programming 2015-2018*, funded by PGMO Gaspard Monge programme, France,
  2. *Optimization in liner shipping*: resulted in several journal article [Monemi and Gelareh, 2017a], [Monemi and Gelareh, 2017a], , [Gelareh et al., 2015e], [Gelareh et al., 2013d] and [Gelareh et al., 2013a]. and several conference submission [Gelareh and Monemi, 2017], [Semet and Gelareh, 2015], [Monemi et al., 2009], [Monemi and Gelareh, 2016], [Monemi and Gelareh, 2017d], [Monemi and Gelareh,], [Danach et al., 2016], [Danach et al., 2014b], [Hanafi et al., 2016], [Gelareh et al., 2016b], and [Gelareh et al., 2015c] among others.

     We have also received the Best paper Award for [Gelareh et al., 2017b] at the Lebanese Conference on Information Systems (LCIS 2017) at Lebanese American University, Beirut.
  3. *Optimization in Crossdock Operation*: resulted in one journal article [Gelareh et al., 2015d] and a conference papers [Gelareh et al., 2013c].
  4. *Modeling Coopetition in Hub-and-Spoke Networks*: resulted in one journal article [Gelareh et al., 2017a].
  5. *Load balancing on the transportation networks*: resulted in one journal submission [Monemi et al.,] and a conference article [Monemi et al., 2017].
  6. *Workover Rig Maintenance Problem: A Brazilian case study*: resulted in a journal article [Monemi et al., 2015] and a conference submission [Gelareh et al., 2015b].
  7. *Network Design in Telecommunication*: resulted in a journal article [Monemi and Gelareh, 2017c] and two conference submission [Monemi and Gelareh, 2017b] and [Gelareh et al., 2016a].
  8. *Selective Traveling Salesman Problem with Pickup and Delivery*: resulted in journal submission, see [Gelareh et al., 2019a].

- **J. Riera-ledesma, Assoc. Professor**, Universidad de La Laguna, Spain: Collaboration in the framework of a research project: *Optimal Traffic Routing in Containers Terminals*.
  This has resulted in a conference submission [Riera-Ledesma and Gelareh, 2014] and a work-in-progress [Riera-Ledesma and Gelareh,].

- **A., Mahmoudirad, Asst. Professor**, Azad University, Iran: Collaboration in the framework of a research project: *Cost Structure in Transportation Network Design* resulted in a journal publication [Sanei et al., 2017].
- **R., Murray, Asst. Professor**, Dublin Institute of Technology, Dublin: collaboration in the framework of *InTrade interreg IVB 2011-2013*: This has resulted in a journal publication [Gelareh et al., 2013b].
- **W. Khalil, Asst. Professor**, Lebanese University, Beirut: Collaboration in the framework of:
  1. A research project: *Hyper-heuristics tailored for large scale transportation (service* network design, funded by a grant from the Lebanese University.
  2. PhD co-supervision:
     - *Hyper-heuristics in Logistics*, K. Danach, 2013–2016, resulted in a joint journal [Monemi et al., 2015] and several conference papers [Gelareh et al., 2015b], [Gelareh et al., 2015b], [Gelareh et al., 2015a], [Danach et al., 2015c], [Danach et al., 2015b], [Danach et al., 2016], [Danach et al., 2015a], [Danach et al., 2014a], and [Danach et al., 2014a].
  3. *InTraDE , Interreg IVB, 2011-2013*: resulted in a conference submission [Gelareh et al., 2012].

1.5.4 National Collaboration

- **A. Nagih, Professor**, LCOMS, Université Lorraine, Metz, France: Collaboration in the framework of:
  - a research project: *Bi-objective Load Balancing Multiple Allocation Hub Location: A compromise programming approach* [Monemi et al.,] and [Monemi et al., 2017].
  - a research project: *Layout planning in the modern elderly houses*
- **R. Merzouki, Professor**, CRIStAL, Polytech'Lille, Université de Lille: Collaboration in a the framework of:
  - *InTraDE Interreg IVB, 2011-2013*: resulted in a journal publication [Gelareh et al., 2013b] and a conference submission [Gelareh et al., 2012].
  - *CoBra Interreg 2Seas, 2018 - 2022*: leading a workpackage on identifying optimal trajectory of niddle in robotized brachytherapy.
- **S. Hanafi, Professor**, LAMIH, Université de Valenciennes, France: Collaboration in the framework of:
  1. *BENMIP: A Generic Benders Decomposition for Mixed Integer Programming 2015-2018*, funded by PGMO Gaspard Monge programme, France,
  2. *Optimization in Crossdocking Operation*: resulted in one journal article [Gelareh et al., 2018].
  3. *Modeling Coopetition in Hub-and-Spoke Networks*: resulted in one journal article [Gelareh et al., 2017a].
  4. *Selective Traveling Salesman Problem with Pickup and Delivery*: resulted in a journal article [Gelareh et al., 2019a].
  5. Co-PI the project *Hybrid Methods in Logistics: Transportation and Mobility*, funded by the regional government of Nord-Pas-de-Calais and ERDF, France

1.5.5 Research Animation

1.5.5.1 Membership of Scientific and Technical Committees (SCs and TCs)

Year	Event	Type
2018	ANT2018, Big Data and Analytics, Portugal	TC member
2017	LCIS2017, Lebanese Conference on Information Systems, Lebanon	SC member
2016	MCDMT 2016 (2nd International Workshop on Modeling, Computing and Data handling for Marine Transportation)	TC member
2013-2017	GOL'14 (Logistics Operations Management)	TC and SC member
since 2013	GECCO - The Genetic and Evolutionary Computation Conference	TC member
since 2013	2nd International Conference on Networking and Advanced Systems (ICNAS 2015), Algeria	TC member
since 2013	PAIS, International Conference on Pattern Analysis and Intelligent Systems, Algeria	TC member
since 2015	2nd International Conference on Distributed System and Decision (ICDSD'2014), Algeria	TC member

In 2015, I have co-organized a Special Session on *Hub-and-Spoke operations in land and maritime transport* together with Dr K. Danach in the *International conference on Computer and Industrial Engineering*, October 28-30 Metz, France.

1.5.5.2 Membership of Working Groups and Associations

During different periods, the following memberships were held.

1. Member of *ROADEF*, since 2012.
2. Member of *European Working Group on Locational Analysis (EWGLA)*, since 2006.
3. Member of *European Working Group on Network Optimization (ENOG)*, since 2007.
4. Member of *INFORMS*, 2014-2016.
5. Member of *Centre for Transportation Studies (CTS)*, National University of Singapore, since 2008.
6. Member of *EASTS -East Asia Society for Transportation Studies*, since 2008.
7. Member of *Operations Research Society of Singapore (ORSS)*, 2008-2010.
8. Associated with the *Centre for Maritime Studies at the National University of Singapore*, 2008-2009.

1.5.5.3 Editorial Board Membership

Since 2013, I am member of Editorial Advisory Board of **Journal of Transportation Research Part E, Elsevier (TRE)**. This journal, is one of leading journals in *Transportation Science Research* and together with parts A, B, C, D and F are the main transportation journals of Elsevier in different contexts. TRE, among other topics, welcomes quantitative methods and modeling that arises in the area of transportation and logistics. It is a very high ranked journal with 3 stars in the ABS ranking. Mathematical modeling, optimization, computational methods, simulation and most of operations research oriented work are accomodated within the scope of part E (TRE). In particular, it has become very established and the main journal for the researchers in maritime transport at Elsevier and even globally.

It should be noted that, since January 2013 when I joined the editorial board, only two articles of us were submitted there (namely [Gelareh et al., 2015e] and [Monemi and Gelareh, 2017a]) and we tend to submit our works elsewhere except for maritime related contributions for which TRE remains the principal journal in particular the frontier of transportation and operational research.

In addition, I am very regularly invited to review submission for *Journal of Computers and Operations Research (COR)*, *OMEGA*, *European Journal of Operations Research (EJOR)*, *Transportation Research Part E (TRE)*, *Transportation Research Part C (TRC)*, *INFORMS Journal of Computing*, *Flexible Services and Manufacturing*, *Journal of Operations Research Society (JORS)*, *Central European Journal of Operations Research (CJOR)*, *International Journal of Management Science and Engineering Management*, *Applied Mathematical Modeling (AMM)*, *Optimization Letter*, *Transport Policy*, *Transportmetrica A: Transport Science*, *Neural Computing and Applications* and *International Journal of Production Research* from among others.

In 2013, I received the **certificate of excellence in reviewing** from the *journal of Transportation Research Part E, Elsevier*.

1.5.5.4 Membership of Evaluation Committees

From 2011 to 2014, I have collaborated with the **Romanian National Research Council (UEFISCDI)** for evaluating the research grant proposals submitted to this agency.

Since 2017, I have been member of the panel of experts for the sub-programme of **Mobility of Growth** of *European Commission H2020* programme.

1.5.6 Funded Projects

During the last few years, I have submitted more than 20 project proposals including a couple of ANR (Agence Nationale de la Recherche) in France, a couple of Google research fund applications, a few Interreg (IVB, 2Seas, Channel) proposals and a H2020 proposal. Some of these are *under review* (first round or second round) and some were unsuccessful. An outline of successful ones can be found in the sequel.

1. **Interreg 2Seas** *CoBra - Cooperative Brachytherapy 2-Seas Interreg Project*: January 2018 - Sep 2022. I lead a workpackage on optimal trajectory planning for robot arm using needle for injecting radioactive seeds in brachytherapy operation for treating prostate cancer.

   The project seeks to develop decision support system for a prototype of a branchytherapy robot developed previously in the framework of SAT-NORD project. Analysis of

patients statistics and requirement (atlas of patients) in the 2Seas region as well as further refinements for paving the way for commercialization are the core parts of this project. Technological software and decision support system for tracking prostate and prescribing trajectory of movement of robot arm for injection and placing seeds given some constraints (including the vicinity of seeds, inflation and deflation of organ during the operation, moving coordinates and re-optimization of trajectory) are among the tasks we assumed in this project.

The lead partner is Prof. Rochdi Merzouki at the University of Lille and other partners are from Netherlands, Belgium and UK.

2. **PGMO - Gaspard Monge programme** *BENMIP - A Generic Benders Decomposition Solver*: October 2015 - September 2019. I am the principal investigator (PI) in this project together with Dr. Rahimeh N. Monemi at CORMSIS Business School, University of Southampton, UK. This project aims at automating the Benders decomposition algorithm and develop a platform that works both as a stand-alone solver and also a C++ API. In the earlier, it is accepting a MIP/MPS file, identifies decomposable structures in the coefficient matrix, performs a Benders reformulation and reports optimal or near-primal solutions. In the latter, the researcher or experienced user can interfere in the process by introducing valid inequalities, efficient separation routines, branching rules, imposing decomposition pattern as well as the corresponding block.

   Other partners at different stages during the period of project include: Prof. Bernard Fortz (Université Libre de Bruxelles), Prof. Dylan Jones, University of Portsmouth and Prof. Said Hanafi at the Université de Valenciennes.

3. **A research collaboration grant from Lebanese University, Lebanon** *Hyper-heuristics Tailored for Large Scale Transportation (Service) Network Design*: October 2015 - Sep 2017. I was the principal investigator (PI) on this project together with Dr. Wissam Khalil at the Lebanese University. This was a funding to pursue and further support the research carried out in the framework of PhD thesis of K. Danach under the common co-supervision with Dr. Wissam Khalil.

   In this project, we have analytically studied and also incorporated the knowledge from data science, artificial intelligence and machine learning into the context of hyper-heuristics in order to extract and exploit information that led to the success of certain heuristics in our portfolio of the most efficient ones.

4. **A Franco-Algerian PHC-Tassili** *Optimization in maritime transport: Port Operations at the Quay Side and Empty Repositioning on the Seaside*: January 2015 - December 2017. I was the principal investigator (PI) in this project together with Prof. Karim Bouamrane from the Université d'Oran 1, Algeria.

   This project aimed at establishing a cross-continental research group on a very specific domain. We have established 4 PhD co-supervision (one of which is an Algerian CIFRE-type thesis) between the two institutions. This project focused on the maritime transport, namely four problems: 1) Optimization of repositioning of empty containers in liner shipping, 2) Simulation modeling and analysis of containers stacking in container terminals with confined spaces, 3) inventory routing in the context of LNG shipping and distribution, and 4) maritime network design. Everyone of these topics is studied in one of the aforementioned four theses.

Some journal articles and conference submissions and a couple of exchanges have been among the results of this project, so far.

5. **ELSAT 2015–2020** *Hybrid Methods in Logistics: Transportation and Mobility*: I am the co-principal investigator (PI) in this project together with Prof. Said Hanafi from the Université de Valenciennes, France. This project is funded by the regional government of Nord-Pas-de-Calais and ERDF.

   This project focuses on the computational efficiency of optimization problems arising in transportation and mobility. For problems ranging from network design, distribution planning and crossdocking, we are carrying out intensive research on design and develop of algorithmic frameworks that combine metaheuristics and exact methods in order to push the limit of solvability of instances of problem that have significant impact on the regional economy.

6. **RPF–Research Project Fund, UoP** *Generalized Service Networks Based on Hub-and-Spoke Structures with Applications in Transportation (and Telecommunications)*: 2017–2018. I was the principal investigator (PI) in this project. This project was funded by the Portsmouth Business School.

   This aims at supporting projects that are aligned with the key focuses of university and will lead to increase its visibility and developing competency in certain area of focus of its research agenda.

   In this project we have modeled coopetition in transportation networks and have used data science concepts and techniques of community detection for identifying communities in the underlying structures that could be used in decomposition techniques and lead to higher computational efficiency.

1.6 Industrial Contracts and Consultancy Activities

I have carried out some consultancy and software development projects. The consultancies are in the following areas:

1. Space management in production sites with confined spaces: I have developed a prototype of a decision support system for carrying out *what-if* analysis in production plant (UK),
2. Business Analytics in finance (developing financial products) (UK, Iran),
3. Container stacking in container terminals with confined spaces (UK and Belgium),
4. Logistics and resource allocation inside hospitals (UK, France),
5. Distribution planning for a pharmaceutical retailer firm (UK, France and Belgium),
6. An integrated and holistic optimization approach to a cellular manufacturing system (production line and inventory, etc.)(Spain),
7. A decision support system for predictive maintenance planning for railways (Middle-East),
8. Predictive maintenance of vessels' engine using IoT, analytics and data science (UK and Middle-East),
9. Optimal pricing and online routing platform for an Uber-like service (Iran).

1.7 Civic Engagement and Administrative Activities

1.7.1 Université d'Artois

At the *Laboratoire de Génie Informatique et d'Automatique de l'Artois (LGI2A)*:

- *Conseil du laboratoire*: Since 2012, I am member of lab's council (conseil du labo) of LGI2A;
- *Commission du budget*: From 2012–2016, I have been co-responsible for the committee for budget at LGI2A.
- *commission API*: Since 2014, I am an *elected* member of API Committee for recruiting ATERs (attachés temporaires d'enseignement et de recherche) and visiting professors.

1.7.2 University of Portsmouth

In 2016-2017, I have been a member of *Center for Operations Research and Logistics (CORL)* at the University of Portsmouth, UK.

1.7.3 Université de Lorraine

Since 2018, I am an associated member of *Laboratory of Design, Optimization and Modeling of Systems (LCOMS)* at the Université de Lorraine, Metz, France.

1.8 Publications

In this section we present the summary of different outputs.

Book(s)

[Gelareh, 2008a] Gelareh, S. (2008a). *Hub Location Models in Public Transport Planning*. PhD thesis, Technical University of Kaiserslautern, Kaiserslautern, Germany. 16

[Gelareh, 2008b] Gelareh, S. (2008b). *Hub Location Models in Public Transport Planning*. VDM Verlag. 15, 36

Articles in International Peer-reviewd Journals

[BGB18] N. Belayachi, S. Gelareh, and K. Bouamrane. The logistic of empty containers' return in the liner-shipping network. *Transport and Telecommunication*, 18(3):207–219, April 2018. 15, 17, 20, 36

[DGM19] K. Danach, S. Gelareh, and R. N. Monemi. The capacitated single allocation p-hub location routing problem: A lagrangian relaxation and a hyper-heuristic approach. *EURO Journal on Transportation and Logistics*, 2019. 17

[GGG+18] S. Gelareh, F. Glover, O. Guemri, S. Hanafi, P. Nduwayo, and R. Todosijevic. A comparative study of formulations for a crossdock door assignment problem. *Omega*, 2018. 21, 38, 41

[GGH+19] S. Gelareh, B. Gendron, S. Hanafi, R. N. Monemi, and R. Todosijevic. The selective traveling salesman problem with draught limits. *Heuristics*, pages 60–79, 2019. 20, 21

[GHMM17] S. Gelareh, S. Hanafi, N. Maculan, and R. N. Monemi. A coopetitive framework for hub location problems in transportation networks. *Optimization*, 66(12):1–18, 2017. 15, 19, 20, 21, 31, 35, 36

[GM17] S. Gelareh and Q. Meng. A novel modeling approach for the fleet deployment problem within a short-term planning horizon. *Transportation Research Part E*, 46(1):27–29, April 2017. 15, 20, 7, 36, 39

[GMM+13] S. Gelareh, R. N. Monemi, N. Maculan, P. Mahey, and D. Pisinger. Single string planning problem arising in liner shipping industries: A heuristic approach. *Computer and Operations Research*, 40(10):2357–2373, 2013. 15, 19, 20, 36

[GMMM13a] S. Gelareh, N. Maculan, P. Mahey, and R. N. Monemi. Hub-and-spoke network design and fleet deployment for string planning of liner shipping. *Applied Mathematical Modelling*, 37:3307–3321, 2013. 15, 19, 20, 36

[GMMM13b] S. Gelareh, R. Merzouki, K. McGinely, and R. Murray. Scheduling of intelligent and autonomous vehicles under pairing/unpairing collaboration strategy in container terminals. *Transportation Research Part C: Emerging Technologies (*, 3:1–21, 2013. 15, 21, 11, 12

[GMSG15] S. Gelareh, R. N. Monemi, F. Semet, and G. Goncalves. A branch-and-cut algorithm for the truck dock assignment problem with operational time constraints. *European Journal of Operational Research*, 249:3, 2015. 15, 20, 36, 38, 41

[GN11] S. Gelareh and S. Nickel. Hub location problems in transportation networks. *Transportation Research Part E*, 47:6, 2011. 18

[GNM15] S. Gelareh, S. Nickel, and R. N. Monemi. Multi-period hub location problems in transportation networks. *Transportation Research Part E*, 75:67, 2015. 20, 23, 18

[GNP10] S. Gelareh, S. Nickel, and D. Pisinger. Liner shipping hub network design in a competitive environment. *Transportation Research Part E*, 46(6):1366–5545, 2010. 15, 19, 16, 36, 40

[GP11] S. Gelareh and D. Pisinger. Fleet deployment and network design and hub location of liner shipping companies. *Transportation Research Part E*, 47:6, 2011. 15, 19, 18, 36, 40

[MDK+15] R. N. Monemi, K. Danach, W. Khalil, S. Gelareh, Lima Junior, Aloise F. C., and D. J. Solution methods for scheduling of heterogeneous parallel machines applied to the workover rig problem. *Expert Systems with Applications*, 42:9, 2015. 15, 17, 20, 21, 37, 38, 41

[MG17a] R. N. Monemi and S. Gelareh. Network design and fleet deployment and empty repositioning in liner shipping. *Transportation Research Part E*, 108:60–79, 2017. 15, 20, 23, 26, 29, 30, 36, 40

[MG17b] R. N. Monemi and S. Gelareh. The ring spur assignment problem: New formulation, valid inequalities and a branch-and-cut approach. *Computer & Operations Research*, 88:91–102, 2017. 15, 20, 24, 38, 40

[SMN+17] M. Sanei, A. Mahmoudirad, S. Niroumand, S. Jamalian, and S. Gelareh. Step fixed-charge solid transportation problem: a lagrangian relaxation heuristic approach. *Computational and Applied Mathematics*, 36:3, 2017. 21

[YGB16] K. Yachba, S. Gelareh, and K. Bouamrane. Storage management of hazardous containers using the genetic algorithm. *Transport and Telecommunication*, 17(4):371–383, April 2016. 15, 17, 20, 12

Invited Talks

[Gelareh, 2008] Gelareh, S. (2008). Fleet deployment in liner shipping: Modeling and algorithms. Logistics in Container Terminals, workshop on Transport Logistics, Singapore, Organized by Centre for Maritime Studies (CMS) and Global Centre of Excellence (Univ. Kyoto, Japan).

Articles in International Peer-reviewd Conferences with Proceeding

[Belayachi et al., 2015] Belayachi, N., Gelareh, S., and Bouamrane, K. (2015). Reverse logistics in the liner shipping industry. Metz, France. CIE45. 15, 17, 20, 36

[Danach et al., 2015a] Danach, K., Hassan, J. A.-h., Khalil, W., Gelareh, S., and Kalakesh, A. (2015a). Routing heterogeneous mobile hospital with different patients priorities: Hyper-heuristic approach. Beirut, Lebanon. IEEE-DICTAP2015. 17, 21

[Danach et al., 2015b] Danach, K., Khalil, W., and Gelareh, S. (2015b). Multiple strings planning problem in maritime service network: Hyper-heuristic approach. Beirut, Lebanon. IEEE- TAEECE2015. 15, 17, 21, 36

[Gelareh and Meng, 2009] Gelareh, S. and Meng, Q. (2009). A possibilistic look at the fleet deployment problem. Riverview Hotel, Singapore. Symposium on Maritime Logistics and Supply Chain Systems. 15, 20, 36, 39

[Gelareh et al., 2015] Gelareh, S., Monemi, R. N., and Semet, F. (2015). Capacitated bounded cardinality hub routing problem in hub-and-feeder network design: Modeling and solution algorithm. Ajaccio, Corsica, France. Odysseus 2015. 15, 20, 36

[Monemi and Gelareh, 2016] Monemi, R. N. and Gelareh, S. (2016). Selective traveling salesman problem with draught limit. Canterbury, UK. CO16 - International Symposium on Combinatorial Optimization. 20

[Monemi and Gelareh, 2017] Monemi, R. N. and Gelareh, S. (2017). Ring spur assignment problem: A branch-and cut. Koper, Slovenia. Joint EURO/ORSC/ECCO Conference on Combinatorial Optimization (ECCO XXX). 15, 20, 38

[Monemi et al., 2017] Monemi, R. N., Jones, D., Nagih, A., and Gelareh, S. (2017). Bi-objective load balancing multiple allocation hub location: A compromise programming approach. Metz, France. MOPGP. 20, 21

[Monemi et al., 2009] Monemi, R. N., Meng, Q., and Gelareh, S. (2009). Impact analysis of mega vessel on productivity and efficiency of container terminals. Singapore. Symposium on Maritime Logistics and Supply Chain Systems. 15, 20, 9, 12, 39, 11

[Semet and Gelareh, 2015] Semet, F. and Gelareh, S., M. R. (2015). The capacitated bounded cardinality hub routing problem: Model and solution algorithm. In *Proceeding of CORAL*, volume 30, Salamanca, Spain. CORAL. 15, 20, 36

[Wang et al., 2009] Wang, T., Meng, Q., and Gelareh, S. (2009). A linearized approach for the optimal fleet deployment with demand uncertainty. In *Symposium on Maritime Logistics and Supply Chain Systems*. Singapore. 15, 20, 9, 36, 39, 11

[Yachba et al., 2014] Yachba, K., Gelareh, S., and Bouamrane, K. (2014). Problem management's investment in shipping containers of goods using a multi-criteria method.

Oran, Algeria. The 2nd International Conference On Distributed Systems and Decision ICDSD14. 15, 17, 20, 36

[Yachba et al., 2015] Yachba, K., Gelareh, S., and Bouamrane, K. (2015). Containers storage optimization in a container terminal using a multimethod multi-level approach. Metz, France. CIE45. 15, 17, 20, 12

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[Gelareh and Monemi, 2017] Gelareh, S. and Monemi, R. N. (2017). Hub-and-spoke network design with circular bi-modal shuttle services. Toronto-Huntsville, Canada. ISOLDE. 15, 20, 36

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[Riera-Ledesma and Gelareh, 2014] Riera-Ledesma, J. and Gelareh, S. (2014). Scheduling of intelligent and autonomous vehicles under pairing/unpairing collaboration strategy in container terminal: Exact approaches. 15, 20, 12

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[Gelareh and Nehi, 2005a] Gelareh, S. and Nehi, H. M. (2005a). Method for evaluating the efficiency of lecturers in an educational institute [in persian]. Ahvaz, Iran. Proceeding of 35th Iranian Mathematical Conference.

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[Riera-Ledesma and Gelareh,] Riera-Ledesma, J. and Gelareh, S. Scheduling of intelligent and autonomous vehicles under pairing/unpairing collaboration strategy in container terminal: An exact approach. Technical report, université d'Artois. in preparation. 20, 21

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Part II

Analytical Overview of Research

Chapter 2

Overview of Research Activities

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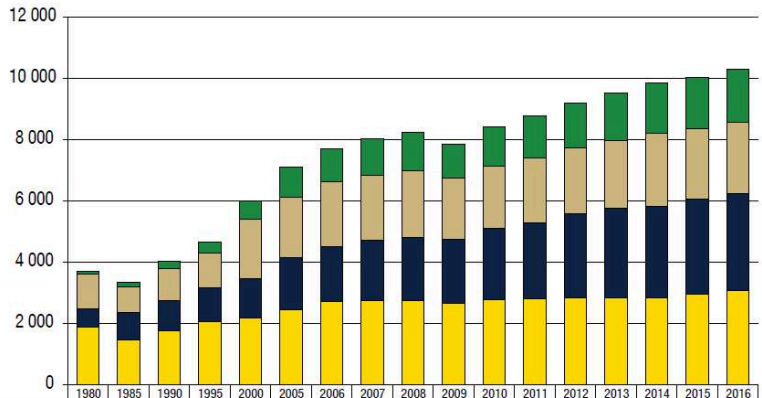
2.1 Introduction

Maritime transportation offers cheaper rates, higher safety levels and less environmental impacts than most comparable transportation modes. The economies of scale exploited by the

concentration of cargo on high-capacity vessels makes it much cheaper to transport cargo with these vessels than with any other mode of transport. Moreover, according to some reports[1], for a given volume of cargo, maritime transport has considerably less environmental impact than alternatives such as air and road transport.

During the last decades, maritime transportation has played a key role in the international trade as the strong and rapid growth in the world economy came along with a larger volume of production (Figure 2.1) and related distribution across the globe. However, increasing focus on environmental issues and the economic crisis in 2009 has made it necessary to consider revisiting the operations in this sector.



	1980	1985	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Container	102	152	234	371	598	1 001	1 076	1 193	1 249	1 127	1 280	1 393	1 464	1 544	1 640	1 661	1 720
Other dry cargo	1 123	819	1 031	1 125	1 928	1 975	2 112	2 141	2 173	2 004	2 022	2 112	2 150	2 218	2 393	2 310	2 339
Five major bulks	608	900	988	1 105	1 295	1 711	1 814	1 953	2 065	2 085	2 335	2 486	2 742	2 923	2 985	3 121	3 172
Oil and gas	1 871	1 459	1 755	2 050	2 163	2 422	2 698	2 747	2 742	2 642	2 772	2 794	2 841	2 829	2 825	2 932	3 055

Figure 2.1 – International seaborne trade, selected years in millions of tons loaded (*Sources: Review of Maritime Transport, various issues. For 2006-2016, the breakdown by cargo type is based on data from Clarksons Research, Shipping Review and Outlook and Seaborne Trade Monitor, various issues.*).

According to [Christiansen et al., 2004], shipping operation can be grouped in three categories: (a) liner shipping, wherein the shipping companies work based on published itineraries made available at the beginning of seasons, (b) industrial shipping wherein the manufacturer or the stakeholder owns its own fleet and ships its own cargo (for example in military, petroleum, LNG industries etc.), and (c) tramp shipping, which operate akin to taxis and collect spot cargo almost anywhere as long as it is profitable.

In this report, we focus on containerized liner shipping that is specialized in providing reliable and regular services among ports along known sailing routes, and it is used in a large extent for long haul transport of high value goods.

Perhaps, the liner shipping industry is one of those industries that has experienced the most serious difficulties and was hit by the financial downturn when it was at its peak of prosperity and evolution. Such a strong hit has forever changed the shape of this industry. This event and transition, besides imposing new composition of players and business models, has also introduced new challenges and novel problem descriptions for researchers in various disciplines to address.

As depicted in Figure 2.2, except for a short period in 2009, the world total volume of

[1]According to the Ministére des Transports du Québec (MTQ), in 2007, for 1 liter of fuel, 1 t of cargo is carried more than 241 km by ship compared to 95 km by train and 28 km by truck.

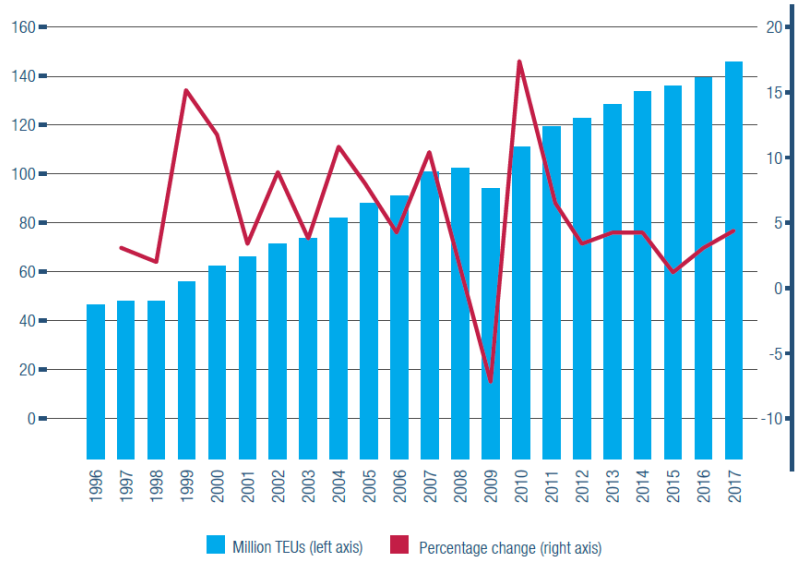


Figure 2.2 – Global containerized trade, 1996-2017, in million 20-foot equivalent units and annual percentage change (*Source: UNCTAD secretariat calculations, based on data from MDS Transmodal, 2017.*).

containerized trade has been increasing steadily over the past two decades. This volume, according to the UNCTAD report, is transported on three major east-west liner trade routes: *Trans-Pacific*, *Asia-Europe* and the *Trans-Atlantic* (see Figure 2.3).

In response to such an increase, as depicted in Figure 2.4, the percentage share of deadweight tonnage of world fleet of containerships has also inevitably increased from 1.6 percent in 80's to 13.2 percent in 2017.

Today, in terms of deadweight, the world fleet is dominated by dry bulk carriers, oil tankers and container ships transporting iron ore or coal [UNCTAD, 2017].

In line with the increase in the capacity, the average containership size has been increasing (except in the recent two years) which again highlights the importance of economies of scale in this sector (see Figure 2.5).

The year 2008, was the peak of vessel delivery in the market by 436 vessels being delivered to a market that was suddenly about to enter into a phase of downturn. In 2016, only 127 new containerships were delivered, representing a reduction of 70 per cent from that peak. In terms of TEUs, this amounted to less than 904 thousand TEUs, a reduction by almost half, compared with deliveries in 2015.

Currently, the industry is witnessing oversupplied market characterized by mega containerships (over 18,000 TEUs) while the overall growth in global demand remains weak. Therefore, the shipping industry has turned to a consolidation and rationalization aiming at optimizing capacity utilization and reduce operational costs. In 2016 and also in 2017, in container shipping industry the consolidation agenda –both in the form of mergers and acquisitions– has been being very aggressively followed and many new regimes and structures are formed in this industry.

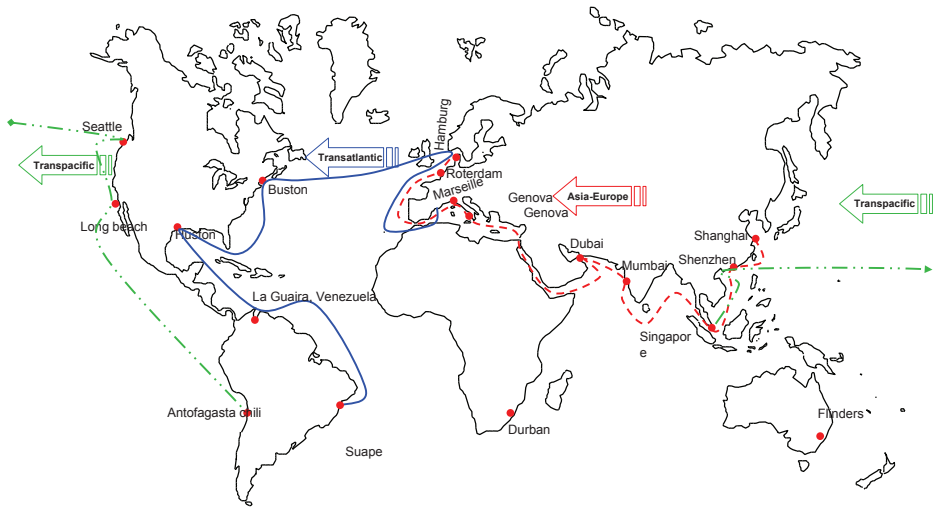
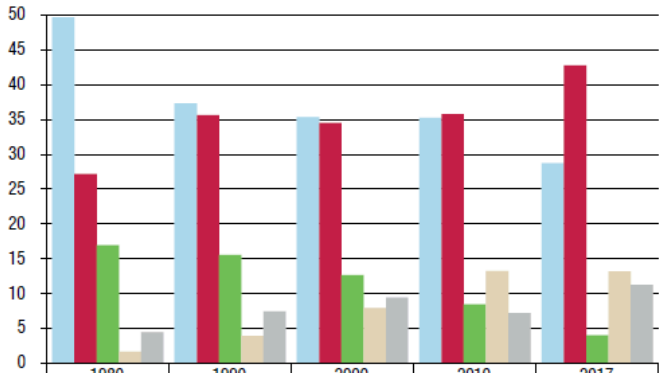


Figure 2.3 – The three major east-west liner trade routes.

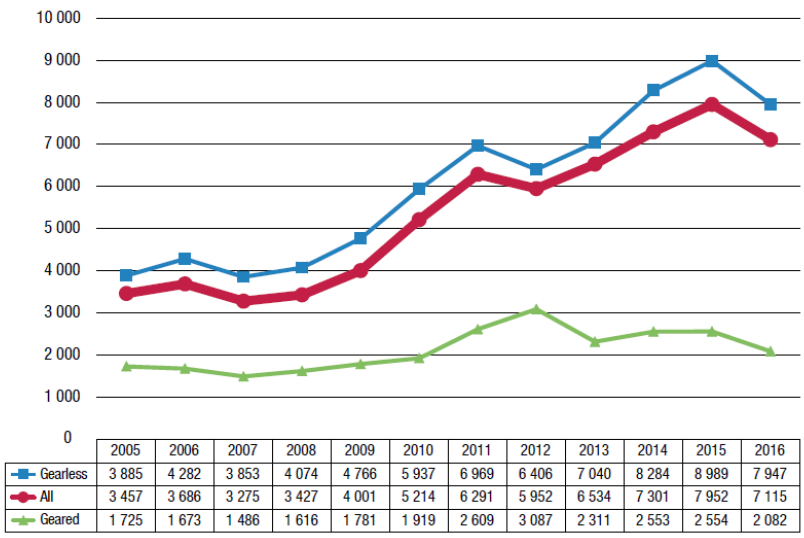


	1980	1990	2000	2010	2017
Oil tankers	49.7	37.4	35.4	35.3	28.7
Dry bulk carriers	27.2	35.6	34.6	35.8	42.8
General cargo ships	17.0	15.6	12.7	8.5	4.0
Container ships	1.6	3.9	8.0	13.3	13.2
Other	4.5	7.5	9.4	7.2	11.3

Figure 2.4 – World fleet by principal vessel type, 1980-2017, by percentage share of deadweight tonnage (*Sources: UNCTAD secretariat calculations, based on data from Clarksons Research and the Review of Maritime Transport, various issues.); beginning-of-year figures.*

Impact on Port Efficiency On the port side, the deployment of mega-ships affected port terminals across the ship-port interface. All the chain up until hinterland, *i.e.* quay, yard, terminal, gate and hinterland operations are being impacted. This is the consequence of tendency in deploying larger vessels, which results in limited maritime access due to the draught restrictions. Therefore, larger container ships normally can only call at fewer ports.

The physical characteristics of such vessels and the handling requirements imposes additional pressure to the quay side operations. In order to minimize the turnaround time of larger-size vessel, terminal operators have to use cranes over longer working hours and more shifts [UNCTAD, 2017].



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Gearless	3 885	4 282	3 853	4 074	4 766	5 937	6 969	6 406	7 040	8 284	8 989	7 947
All	3 457	3 686	3 275	3 427	4 001	5 214	6 291	5 952	6 534	7 301	7 952	7 115
Geared	1 725	1 673	1 486	1 616	1 781	1 919	2 609	3 087	2 311	2 553	2 554	2 082

Figure 2.5 – Average vessel size of container ship deliveries, 2005-2016 in twenty-foot equivalent units (*Source: UNCTAD secretariat calculations, based on data from Clarksons Research. Note: Propelled seagoing merchant container vessels of 100 gross tons and above.)*.

As depicted in Figure 2.6, in spite the fact that the container ship sizes has been increasing over the past 20 years, still the turnaround times have been significantly reduced, owing to the redesign of terminals' layout, expansions, technological development, etc., which helped to cope with the ever increasing volume of containerized freight.

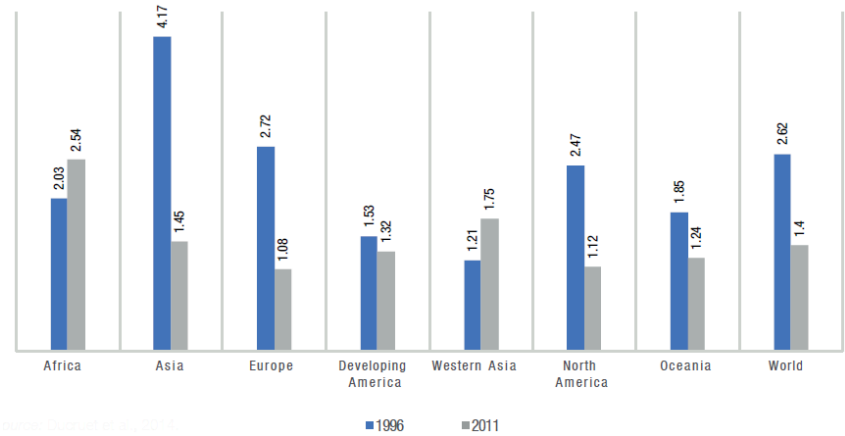


Figure 2.6 – Container port turnaround time, 1996 and 2011 in number of days (see [Notteboom et al., 2014]).

Larger container vessels need to be highly utilized in order to exploit economies of scale. Higher utilization is often associated with lower service frequency. Less frequent calls, but greater cargo volumes being handled per call. This imposes pressure on the yard operation. This in turn create greater demands on gate access, meaning that more trucks arriving and leaving with larger numbers of containers being imported/exported. The consequence is more local congestion as more trucks are waiting to enter the port.

Stressing Ports At the end of the day, large container ships provide economies of scale at sea, but these economies do not necessarily extend to ports. [Guan et al., 2017] stated that a 1 per cent growth in ship size and its auxiliary industry operations increases time in port by nearly 2.9 per cent and creates diseconomies of scale at ports, indicating that economies of scale that are gained at sea are lost at ports .

Ports Loosing Connections In order to maximize utilization of vessel and expand over a wider geographical region, alliances are formed. As ships and alliances become larger, a more limited number of ports and terminals can accommodate their ship calls. The secondary port (non-hub ones) with lower volume of supply and demand and weaker bargaining leverage, will not be called directly anymore because their expansion and development cannot catch up with the expansion scale in shipping.

As the mega-alliances tend to establish more direct calls between port pairs, this type of direct mainline services become more frequent. This threatens the transshipment hub ports, as they are more vulnerable to market share volatility and are under pressure of competition to increase productivity and reduce prices as liners can easily switch to competing ports (Drewry Maritime Research, 2017). On the contrary, the ports with a mix of gateway cargo and transshipment are more resilient to such a practice [Notteboom et al., 2014].

Retrospective 2008 In 2008, when we started to focus on liner shipping industry, the practitioners and academics were expecting some other changes as well. This was *Panama canal* expansion project, which was suggesting new class of vessels –something beyond the *Panamax*, namely the ones called *Neopanamax*, today.

In that period, the world largest vessel was *Emma Maersk* (with a capacity of 11,000 to 15,000 TEUs based on different measurements), the liner shipping industry was expecting to receive larger container vessels as game-changers within the world fleet of container vessels. This was then followed by placing order for containership of class Triple-E with capacity of 18,000 TEU and today, the largest container vessel is *Madrid Maersk* with slightly above 20,000 TEU capacity.

Many smaller port in Europe were no longer called by liners. The remaining ports were expected to have a very high efficiency and minimize the turnaround time of vessels as a vessel is generating revenue when it is sailing not when it is berthed or is waiting for berthing[2]. Even if a small port had sufficient draught, for increasing the efficiency of loading/unloading operation additional spaces were required, an unrealistic criteria, due to being bound to some urban restrictions (historical yards, residential areas etc.).

In addition to the larger vessels and higher volumes on board, the container shipping industry was moving towards having more and more 40-ft equivalent unit (FEU) containers. The 1-FEU containers were more attractive because first of all the manufacturing cost per unit of volume in 1-FEU was significantly cheaper compared to two 1-TEU containers and secondly, they could result in better efficiency at loading/unloading operation and in line with the interests of both port operators and shipping companies. But this was causing

[2]When berthed and loading/unloading is in progress, as the crew are paid for their waiting time, some liner companies refer to this as *hotel* cost

further pressure on ports, as ports had to deploy more and more 40-ft transporters. This was making a serious traffic congestion problem for the smaller ports with confined spaces, which are the majority in Europe, in particular in the North-West Europe region.

It was by itself a complex situation until the signs of recession in 2008 showed up and confirmed in 2009. Major container terminals including the Asian ones were operating with only a fraction of their capacities (*e.g.* the operating quay cranes), vessels were mostly operating under-utilized (or even laid up) and the notion of *slow steaming* was repeatedly being used in the community, some regions have been declared as piracy-ridden waters, some ports were pushed out of the market (and it took sometime for them to start a different business. *e.g.* port of Ostende got involved in the offshore wind energy technologies and become an Energy port), and many other issues.

This revolution resulted in lots of concerns for different players in this industry while new problem descriptions, challenges and opportunities for the academic communities have emerged.

2.2 One Side of the Story: What Ports Are Concerned About?

At the first place, the port operators and port authorities were very concerned because the main hub container ports such as port of Singapore, which is among the world leading ports in terms of efficiency, could be significantly affected by such mega container vessels. Any minimal inefficiency, would have encouraged the liners to shift their calls to Hong Kong — the traditional regional rival.

From the stand point of a port operator, the problem description was the following: *In the short term, we can assume that the liner shipping industry is not ready to introduce any major change and the fleet composition will gradually change in a mid-term horizon. If one operator from among the Liner Shipping Companies (LSCs) that is currently calling at this port, decides to acquire a number of larger vessels, what would be the optimal (with respect to the cost) fleet deployment strategy for it to adopt? what vessel class and in what quantity will be deployed on a given service route? what would be the optimal sailing speed on different legs of call to respect the time windows? what strategy will the LSC adopt for managing its fleet (*i.e. *what type of vessels will charter-in and vessels of which class will be chartered out)?* .

This problem was known as Fleet Deployment Problem (FDP) and has its root in [Nicholson and Pullen, 1971].

For several years (*i.e.* 2000-2008) the literature of Fleet Deployment Problem has not been witnessing any new achievement. The latest work on FDP at that time was a literature review paper [Perakis, 2002]. Modelers were facing difficulties as on the one hand, the realistic modeling would make model too involved and therefore intractable for the general-purpose MIP solvers of those days and on the other hand, a simplistic modeling would have been ending up with unrealistic solutions. Therefore, most of the existing modeling approaches were based on linear programming and only a very few integer programming one.

We carried out a new modeling for the problem of fleet deployment in short-term horizon [Gelareh and Meng, 2017] with the following assumptions, resulting in a good approximation of real practice:

Assumption	
Port Calls	Double calls to a port are handled by assigning different port designations to each one of the calls. There is no two simultaneous calls, arrival or departure to and from a port
Vessel's Location	All the vessels are initially at origins
Cargo	Is generated evenly throughout the planning horizon. Demand over the planning horizon is independent of frequency and is *a priori* known
Service Frequency	Follows the conventional definition as the time between two consecutive departures (arrivals) from (to) a given port on a route during current season
Back-haul	In the case of imbalance, containerships will always have empty containers
Port charges	Are dropped from the formulation
Speed	No difference between ballast and full load sailing speeds is assumed
Fuel Cost	Is constant
Turnaround Time	Is included in the definition of travel time
Maintenance	Is not considered within the short-term planning horizon
Voyages	Are completed within a short-term season

The resulting model is a $\mathcal{O}(|S||R||L|T|)$ mixed integer nonlinear programming model where $|T|$ represent the length of planning horizon, $\mathcal{S}$ stands for the set of vessels, $\mathcal{R}$ is the set of service routes for the given LSC and $\mathcal{L}$ represents set of legs of call. This model was still computationally challenging. The nonlinearity was mainly due to the decisions on the sailing speed on different legs of call. However, at that point in time, the MIP solvers were by far more efficient compared to the 90's and the linearization of this nonlinear formulation –which came at the cost of introducing additional variable but was still of $\mathcal{O}(|S||R||L|T|)$– was not computationally as prohibitive as a few years before it.

It is commonly known in liner shipping that the major cost component is the bunker cost and any fleet deployment problem –with the objective of cost minimization– normally integrates such a cost structure in its objective function.

In order to linearize this model it is assumed that we can, for every leg of call, derive the cost function as a function of travel time. This could be replaced within the nonlinear model and achieve a linear one, if ΔT could be chosen judiciously. This is possible because the sailing speed interval for every vessel class is practically very narrow and does not vary a lot. The idea is to replace the calculation with constant values (representative of every interval) of a step function and in this way, avoid the unnecessary nonlinearity.

Figure 2.7 depicts the cost function as a function of travel time on a given leg of call. As one observes in Figure 2.7, to every vessel class, a design speed is attributed which determines the speed at which the vessels bunker consumption cost is minimized. This point coincides with the speed at which shipping companies operate when they are in *slow-steaming* mode.

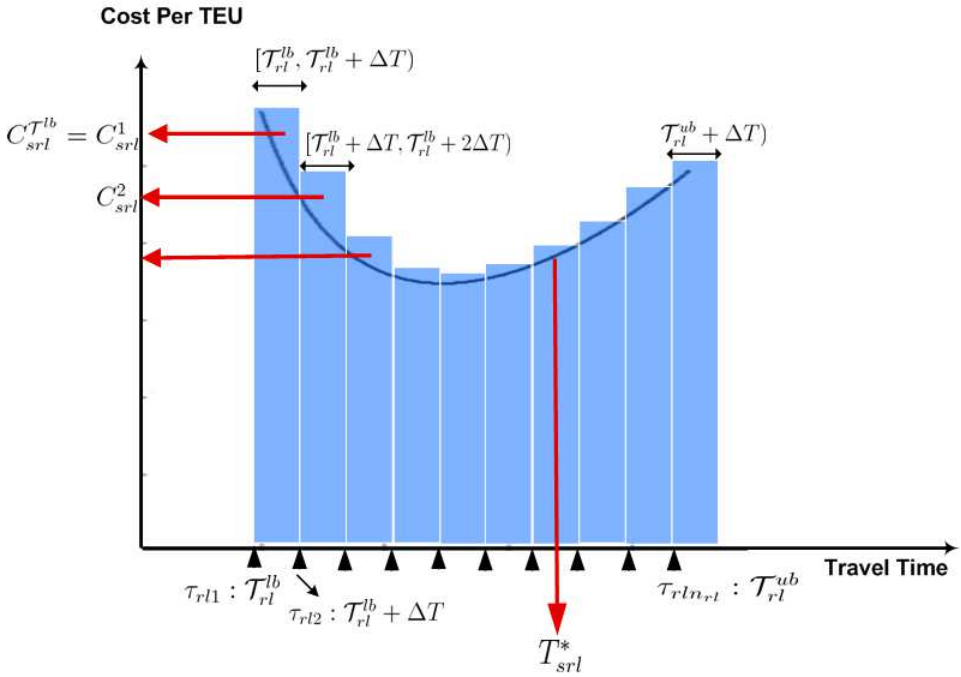


Figure 2.7 – Cost as a function of a travel time.

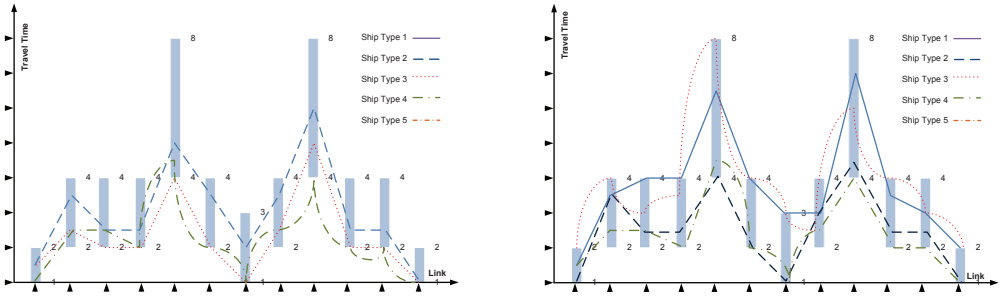
We assume that the company is operating with limited type of vessels (even if chartering is involved). The vessels of first category have a (effective and not nominal) a capacity up to 4,000 TEUs. Second, third, fourth and fifth are, respectively, introduced for 6,000, 8,000, 10,000 and 12,000 TEUs. It is also assumed that depending on the season there are limitation on the maximum number of available vessel to charter in. The liner shipping company is interested in knowing the optimal fleet deployment scenario in case of this instance.

In Figure 2.8, we demonstrate the optimal deployment strategy of an instance (corresponding to a single route) reported by the optimal solution of the linearized model. Each rectangular block represents a voyage link and its height corresponds to the travel time (time line) on that link.

Figure 2.8 (a) reports the optimal deployment in the absence of mega vessels (only up to the 4-th vessel class) on the service route, and Figure 2.8 (b) depicts the optimal deployment of fleet composed of all five types of vessel. One observes that on this route as one of the busiest routes, the vessels of smaller size like type 1 did not appear in the optimal solution as they are offering lower economy of scale. The vessels of the second type are operating in the average level travel time as it is more beneficial for them not to sail very fast nor very slow. For the type 3 and 4, in most of the cases it is more beneficial if they sail as fast as possible and facilitate provision of more service, as is shown in Figure 2.8.

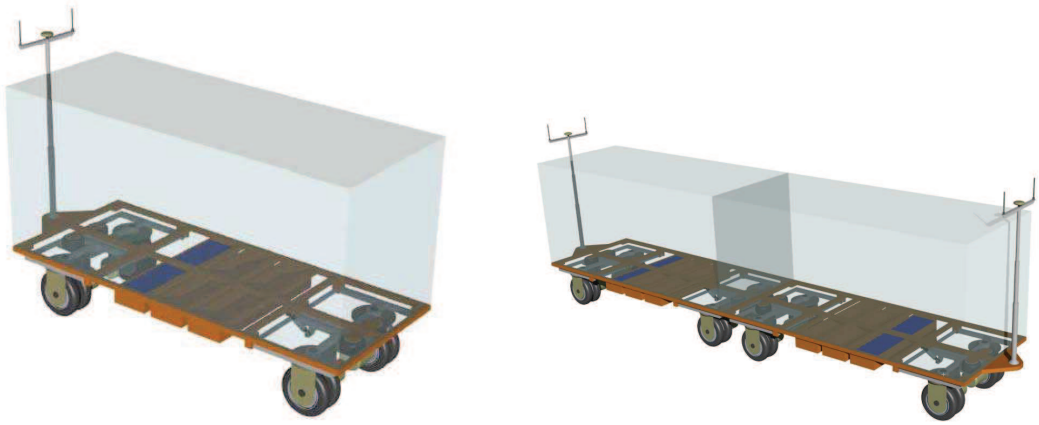
Subsequently, we proposed a discrete-event simulation model based on queuing networks to simulate the terminal environment (including the quay side and yard side operations) and carried out a *what-if* analysis under the scenarios corresponding to the FDP optimal solutions. The results of impact analysis of mega-vessels on the port operation efficiency are reported in [Monemi et al., 2009].

In [Wang et al., 2009], we studied fleet deployment problem under demand uncertainty



(a) Using mega-vessels. (b) Without mega-vessels.

Figure 2.8 – Optimal fleet deployment.



(a) 1-TEU IAV. (b) 1-FEU IAV.

Figure 2.9 – Intelligent and Autonomous Vehicles (IAVs).

resulting in nonlinear models that were lienarized to achieve computationally well-behaving model.

Later, again in the framework of InTraDE (Interreg IVB[3]), we continued to work on the optimal traffic management inside the container terminals with confined spaces. In InTraDE, the technological part of the consortium, has designed and developed a new class of Automated Guided Vehicles (AGVs) referred to as Intelligent Autonomous Vehicles (IAV). These vehicles are technologically superior to the existing AGVs, in many respects. They offer more flexibility and intelligence in maneuvering within confined spaces where the logistic operations take place. This includes the ability of pairing/unpairing enabling a pair of 1-TEU IAVs dynamically join, transport containers of any size between 1-TEU and 1-FEU and disjoin again (see Figure 2.9). Deploying IAVs helps port operators to remain efficient in coping with the ever increasing volume of container traffic at ports and eliminate the need for deploying more 40-ft transporters in the very confined area of ports.

[3]http://www.intrade-nwe.eu

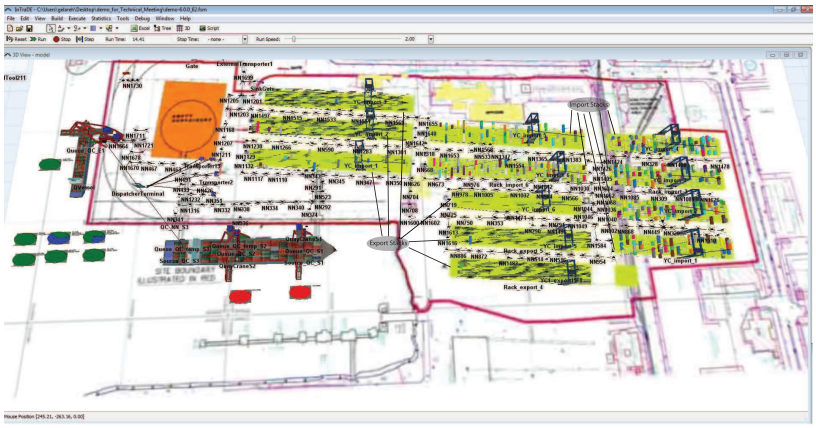


Figure 2.10 – The Flexsim simulation model of Dublin terminal.

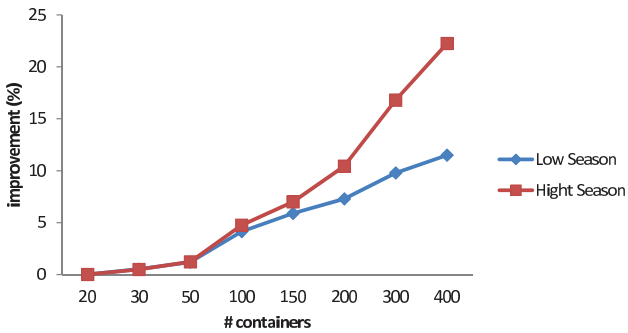


Figure 2.11 – Improvement over current practice in *low* and *high* season.

We worked on two case studies, *Dublin Ferryport Terminal* and the port of *Radicatel* in France. The problem concerns events in a highly dynamic environment and is an online problem by nature. Two scenarios were considered: 1) using AGVs with a fleet composed of 20-ft and 40-ft transporters and 2) an equivalent capacity but using IAVs.

The off-line version of the problem was modeled as a scheduling problem and solved by a Lagrangian relaxation-based decomposition approach equipped with a variable fixing procedure and a primal heuristics to obtain high-quality solution of instances of the problem. Some of the results have been reported in [Gelareh et al., 2013b].

For the online version, a simulated environment has been developed for every terminal (see the case of Dublin in Figure 2.10), which imitated the operation during a given planning horizon. Dispatching rules, inspired by the patterns found in the solutions to the off-line problem were used as rules for dispatching operations and an extensive simulation study has been carried out.

The results indicated that a potential gain resulted by deploying such transporters during high season can be up to 23 per cent saving in time while in low season it can be up to 13 per cent.

2.2.1 Summary of Research Activities

In what concerns port operations, the following activities have been carried out:

- One completed PhD thesis (K. Yachba, in co-supervision with the University of Oran 1, Algeria),
- A peer reviewed ABS-ranked journal article ([Gelareh et al., 2013b]) plus a couple of peer-reviewed conference papers jointly with the students ([Yachba et al., 2016], [Yachba et al., 2015]) and a few others with fellow colleagues ([Monemi et al., 2009], [Riera-Ledesma and Gelareh, 2014], [Gelareh, 2013] and [Gelareh et al., 2012]).

2.3 The other Side of the Story: What Liner Companies are After?

LSCs operate a set of *strings* and every string is traditionally managed by a *string manager*. As in many other industries, there is barely a standardized and unique definition of the terms. A string manager decides on 1) which ports and in what order must be called on a rotation (starting from a given port vising others on this rotation and returning to the starting port), 2) what type of vessel to be deployed on it (possibly chartering in some voyages) and, 3) a good approximate of number of containers to be picked up from or delivered to the ports on the rotation (perhaps to serve regional demands). A typical global network of a major liner shipping company is depicted in Figure 2.12. The service frequency along every string is typically one week.

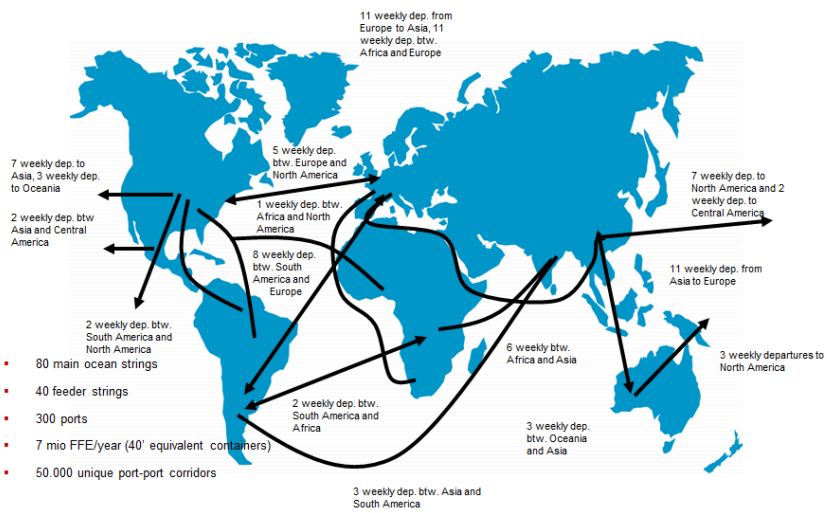


Figure 2.12 – The global network of a major liner composed of different strings.

Given the aforementioned description, one can define a string as a rotation plus the origin-destination (O-D) demands and the vessel class associate to it. We tend to not include sailing speed in this definition of a string because the (design) speed is dependent on the vessel class. However, it must be noted that the sailing time along a rotation is (roughly) multiple of weeks in order to maintain a regular weekly frequency using an integer number of vessels.

Such round trips are either 1-3 weeks long rotations, which are known as *Feeder* services or 4-12 weeks round trips, which are called *Main* services. The latter are often called *ocean-going* services, as well (see Figure 2.13).

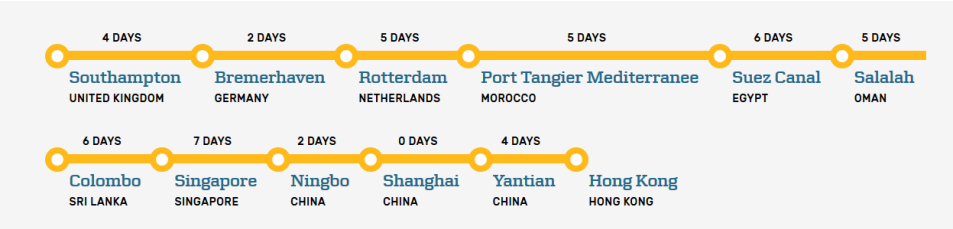
Figure 2.13 – A typical round trip.

Figure 2.14 depicts the service rotation Asia-Europe (AE1) operated by MaerskLine (by the time this report being written).

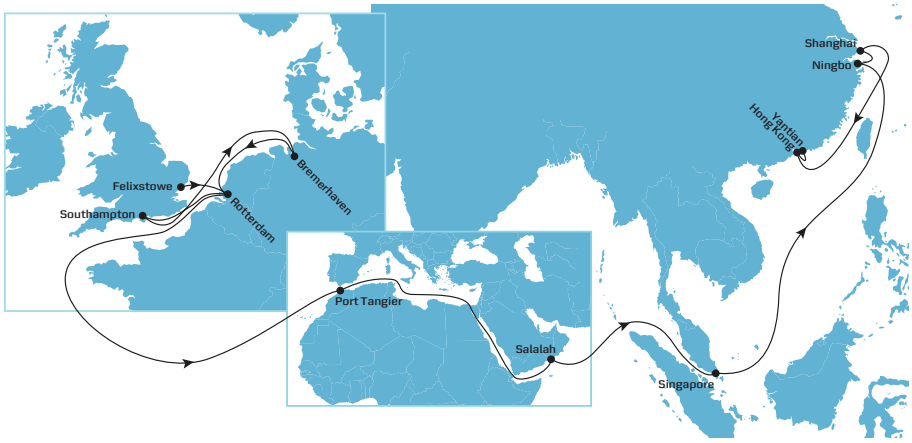
The corresponding timetable (published itinerary) is reported in Figure 2.14a.

Port call	Transit time	Arrives	Departs
Southampton	–	–	Day 1 (Wednesday)
Bremerhaven	4 days	Day 3 (Friday)	Day 5 (Sunday)
Rotterdam	6 days	Day 6 (Monday)	Day 7 (Tuesday)
Port Tangier Mediterranee	11 days	Day 11 (Saturday)	Day 12 (Sunday)
Suez Canal	16 days	Day 16 (Thursday)	Day 17 (Friday)
Salalah	22 days	Day 22 (Wednesday)	Day 23 (Thursday)
Colombo	27 days	Day 27 (Monday)	Day 28 (Tuesday)
Singapore	33 days	Day 33 (Sunday)	Day 34 (Monday)
Ningbo	40 days	Day 40 (Sunday)	Day 41 (Monday)
Shanghai	42 days	Day 42 (Tuesday)	Day 43 (Wednesday)
Yantian	42 days	Day 47 (Sunday)	Day 47 (Sunday)
Hong Kong	46 days	Day 46 (Saturday)	–

Another very important point to highlight is that approximately 50% of the total transportation volumes experiences 1 or more transshipments along every O-D path (see Fig-



(a) Graphical representation.



(b) Intuitive representation.

Figure 2.14 – The rotation (sequence of calls) on Asia-Europe line 1 (AE1), (www.MaerskLine.com).

ure 2.15) —basically they operate on Hub-and-Spoke structures.

Figure 2.15 – Direct vs transshipment.

We would like to reiterate on a couple of points before moving forward. The ports were assuming that: 1) the world fleet of containerships will have a significantly different composition, 2) the service network will be impacted and, 3) the major ports will have to receive and efficiently handle larger vessels.

In the early years only a couple of liners (headquartered in European) were operating such kind of vessels. The first two networks that were subject to any change belonged to these two operators.

2.3.1 Network Design for a Duopoly Market in Competitive Environment

This problem addresses the competition between a newcomer liner service provider and an existing well-established operator, both operating on hub-and-spoke networks. The newcomer company maximizes its market share –which depends on the service time and transportation cost– by locating a predefined number of hubs at candidate ports and designing its network.

The problem description follows: *Given a finite set of ports $H = \{1, 2, ..., N\}$, demand between O-D pairs ports and a liner transport service provider $\mathcal{A}$ that has already established its Hub-and-Spoke transportation network on this set of nodes using q hubs, while the rate of offered service and travel time between each pair of ports i and j are known to be $C_{ij}^{\mathcal{A}}$ and $T_{ij}^{\mathcal{A}}$, respectively; we seek an optimal design of a hub-and-spoke network of service provider $\mathcal{B}$ with p hubs in total (perhaps some coinciding with the hubs of $\mathcal{A}$) so that a weighted sum of the total attractiveness of the services due to the lower rate and shorter service time is maximized.*

As the classical discrete choice models were not suitable to this application area, we introduced an attraction function to indicate the number of customers that can be attracted to the newcomer liner service provider based on time/freight rates. The observations from historical data revealed that this function has an *inverse hyperbolic cosecant* form (in the first

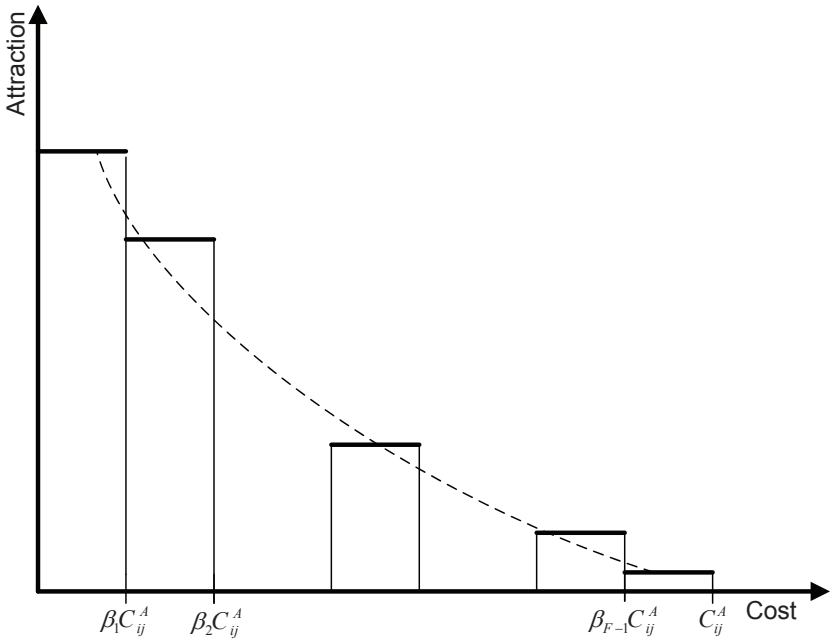


Figure 2.16 – Attraction function approximated by a step-function.

quadrant) and as shown in Figure 2.16, it can be approximated by a step-wise function.

In [Gelareh et al., 2010], we proposed a mixed integer programming (MIP) model for the COMPETITIVE HUB LOCATION PROBLEM (CMPT-HLP). The considered objective function was a convex combination of attractiveness in terms of both cost and time. The transportation cost/time for a given flow with origin i and destination j accounts for the sum of, (i) the cost/time of sending the flow from i to the first hub node, (ii) the transshipment cost/time (including unloading, holding, and re-loading) at the first hub port, (iii) cost/time of traversing one or more hub edges discounted by the factor α $(0 < \alpha < 1)$, reflecting the relative factor of economies of scale for the given vessel, (iv) transshipment cost/time at the last hub port and, (v) the cost/time of transportation on the last spoke edge.

While general-purpose solvers could not solve instances of even small size, an accelerated Lagrangian method combined with a primal heuristic has been proposed that obtained promising bounds and very high quality solutions were reported in a very reasonable computational time.

2.3.2 Network Design and Fleet Deployment

Today, more than 830 port around the globe are involved in the transport of containers. While some of these ports are origin/destination of significant amount of containers, there are also others with demand of one container per week (but still counted in the total 830)[4]. Figure 2.17 depicts distribution of such ports around the globe.

As mentioned earlier, there are two type of services: regional *feeder* service and *main*

[4]In practice, in order to achieve a computational efficiency, one needs to do a preprocessing and aggregating the small ports to artificially located ports with meaningful supply/demand.

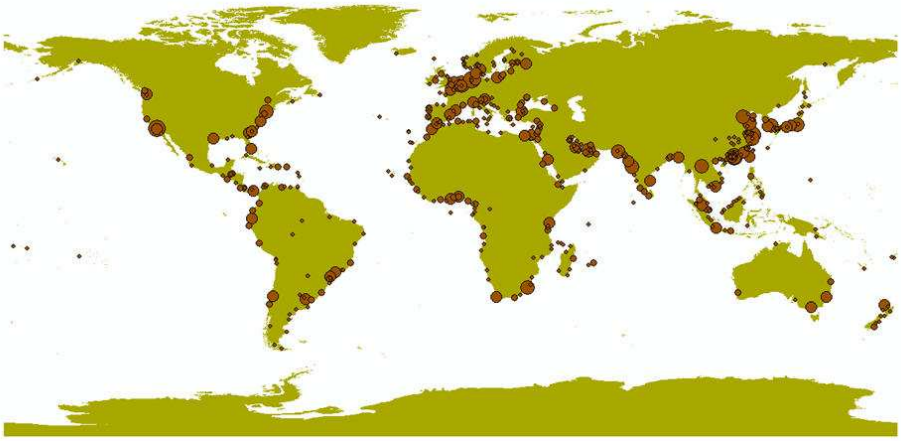


Figure 2.17 – Approximately 830 ports send and receive containers.

services.

Feeder services The feeder service are regional services for shorter distances and using smaller size vessels. Normally, the internal origin-destinations demand of the region are served by such services. Moreover, such services accumulate smaller quantity supplies of regional spoke ports and deliver as a higher quantity to the regional hubs and distributing the large supply of regional hubs into smaller quantities.

The reason why some ports become regional spokes is because either their demand and supply are very small or even if (in an unlikely event) the supply/demand would be significant, such ports do not have physical characteristics and/or infrastructure required for being a hub port and being called by larger vessels.

In the regional feeder level, normally the rotations of the same liner company have less intersections and transshipment does not take place among rotations.

Main services Long-haul shipping allows larger vessels realize economies of scale. For the shippers, it is only the sailing vessel that generates profit and too many calls at too many ports will reduce the profitability of service as it increases the idle time of vessels, berthing and the cost of loading/unloading as well as crew cost. Therefore, in longer distances the liners prefer to not call too many neighboring ports and the number of ports along the ocean-going rotations is rather limited. Instead, the global shipping network of a liner shipping company is composed of several rotations. These rotations often intersect or pass through common points, which are used as transshipment ports. At these transshipment ports, the containers are delivered to different vessels on different routes to be routed to their destinations.

2.3.3 Fleet Deployment, Network Design and Hub Location of Liner Shipping Companies

A major liner company operates several ocean-going strings as per Figure 2.12. We have defined four phases in our long term project and went through them step-by-step as follows: 1) feeder-level network, 2) one main string passing through several feeder services, 3) several main service and several feeders and also taking into account the ports that are not visited even by the feeder services and, 4) economic oriented model of networks dealing with the aspects of alliance formation, cooperative and coopetitive operations.

2.3.3.1 Phase I: Single Regional String Planning

In [Gelareh and Pisinger, 2011a], we studied a structure containing one feeder service and regional ports along it as well as those ports that are not served directly but served by a third-party player.

The FLEET DEPLOYMENT ON A HUB LOCATION NETWORK (FDHLN) is formally stated as follows: *Given a set of ports each of which has at least one container terminal and also given the O-D flows between every pair of ports, a finite fleet of vessels of certain types with respect to capacity, size and particular traits, the running cost per unit of TEU for every vessel type and for every leg, the revenue generated per unit of flow for every vessel type and every leg of call, the fixed deployment cost for every vessel type (independent of leg of call) and, the transshipment cost per unit of flow (TEU) at every port along an O-D path. We seek a cyclic route (hub-level round-trip sub-network) in the region of service passing through a set of designated regional hub ports, such that the remaining non-hub (spoke) ports send their demands using third-party feeder vessels to a finite and limited number (usually restricted to two) ports on the circular route. Such a solution is characterized by: 1) a directed hub-level circular route subject to a bounded travel time, 2) allocation of the spoke ports to the hub ports on the circular route, 3) assignment of optimal vessel type and frequency to each spoke link, 4) determination of the fraction of the O-D demand to be fulfilled and, 5) assignment of an optimal number of a unique vessel type on the circular route. We seek an optimal solution of this problem such that the overall return after deduction of costs (transport, deployment, transshipment) is maximized.*

In this problem, it is assumed that the demand is evenly generated over the planning horizon. This is a safe and practically accepted one since in practice a major part of demand is generated by the top few customers.

Figure 2.18 sheds more light on the structure of such a network. A very important point to be taken into account is the fact that at the very regional level, there are ports that are not visited even with the feeder services. These nodes in the network are spurred to other ports on the regional feeder rotation. Moreover, the flow is elastic in this model.

We have proposed a mixed integer programming formulation and a Benders decomposition [Benders, 1962] algorithm for solving this problem based on our success in primal decomposition techniques (*e.g.* Benders method [Benders, 1962]) on large instances of Hub Location Problems in [Gelareh and Nickel, 2011] and [Gelareh et al., 2015e]. In the master problem, which is the design part, the connectivity is not maintained using sub-tour elimination constraints. Rather we opted for using a different graph model presented in [Maculan et al., 2003] and depicted in Figure 2.19. In addition, the algorithm was equipped with preprocessing and variable fixing procedures, symmetry-breaking, explicit constraint branching [Appleget et al., 2000] and non-dominated cut generation [Magnanti and Wong, 1981] techniques.

This achieved better computational performance compared to using sub-tour elimina-

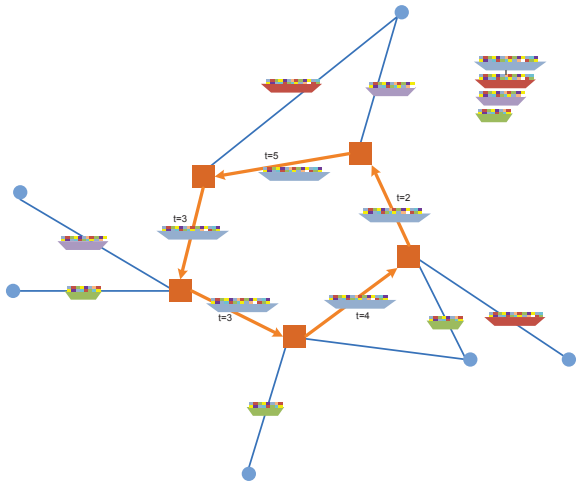


Figure 2.18 – A hypothetical solution to the problem. Four vessel types are available as illustrated in the upper right corner. The hub network is marked with red (square nodes and connecting directed links), while the feeder lines are marked with blue (circles and undirected links). Type of vessel is indicated on the edges.

tion because even for fractional values of the design master problem, the flow subproblem remains feasible and we avoid saturating the master problem by generating non-improving feasibility cuts. However, we were still only able to solve very small size instances within reasonable time.

2.3.3.2 Phase II: Multi-Feeder/Single-Ocean String Planning

The regional feeder rotations are served by ocean-going services. Normally, an operator operates no more than one ocean-going service route for a given group of feeder services. Therefore, one (and very exceptionally, two) major ports along every regional route are called by a given ocean-going service (for the aforementioned profitability reason).

The volume of flow to be delivered to the feeder strings plays a very crucial role in the choice of vessel class to be deployed on the ocean-going string. Along an ocean-going service, each port is called at no more than twice, although a single port may be called at several times on different strings. The size of string dictates the number of vessels required to offer a given frequency of service.

Cost structure In [Gelareh et al., 2013a], we have been provided by the data of three anonymous LSCs on the operating cost of various vessel sizes and their total transported TEUs, as well as vessel displacements for a given planning horizon. Figure 2.20 depicts the variation in the cost per TEU against the capacity of vessels. We can see that cost per TEU varies relative to vessels' actual utilization of capacity rather than varying relative to their ideal maximum utilization.

One would expect to find that larger vessels are more cost effective per TEU. However, looking at Figure 2.20, we see that medium sized vessels are the most cost effective per TEU, and therefore, the most viable ones. This is because of the low average utilization of vessels over the whole sailing horizon. It is nevertheless vital for LSC's to have high capacity vessels

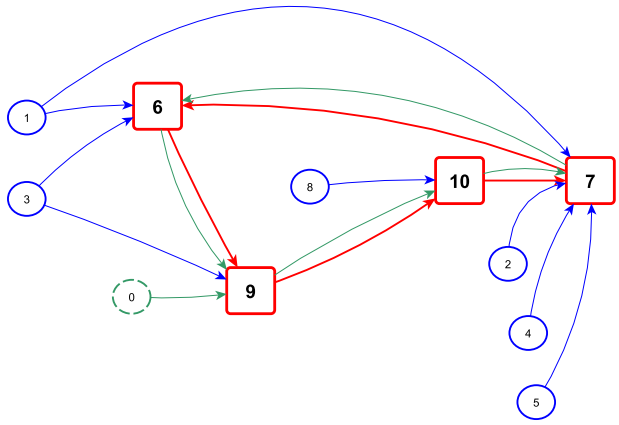


Figure 2.19 – Dummy node '0' sends one unit of flow for those selected node taking part in the cycle.

available in order to cope with fluctuations in demand.

In liner shipping, the whole network is revised at least twice per year. Usually, before every season starts (a season being a 3-6 months long), the policy makers of each LSC decide on seasonal configuration of the network based of the historical data and forecasted demands (as well as experts' knowledge of the market and general management policies). Therefore, the multiple string planing problem is of very high importance, although it had not received much attention at that time.

What we refer to as P-STRING PLANNING PROBLEM (P-SPP) is described as follows: *p-SPP seeks one single main string rotation. For this we require the following information: a certain number of ports, n, O-D flows between every pair of ports, the transit time for every leg of call, a set of candidate LSCs (already operating on their service rotations) and a given minimum service level (currently weekly) in terms of frequency of visiting every port. The one single main string rotation sought by p-SPP operates with $p < n$ ports, where each port on the rotation is a starting port for one of the p feeder rotations* (i.e. *a partitioning of a given number of nodes to p feeder rotations), each of which forms a directed rotation starting from a node on the main rotation, visiting all other nodes in the same feeder rotations and finally returning to the origin string port. There is a limited quantity of vessels $v \in \Lambda$, and only vessels of the same class may operate on one string (main rotation or feeders). The objective is to meet all demands whilst properly allocating shipping capacities in order to minimize the weighted-sum of transit time and the total fixed deployment cost.*

The network structure of this problem is depicted in Figure 2.21. As one observes one ocean-going rotation calls at a single port per feeder rotation in every region.

In order to minimize the weighted sum of transit time, and fixed deployment costs, we proposed a mixed integer linear programming model of the network design, and an allocation of proper capacity size and frequency setting for every rotation. Given that none of the existing general-purpose MIP solvers were able to solve even very small problem instances in a reasonable time, we proposed a Lagrangian decomposition approach, which uses a heuristic procedure and is capable of obtaining practical and high quality solutions in reasonable times. The model is applied on a real example and the results reported in [Gelareh et al., 2013a] showed how it suggests a better management of assets and delivers

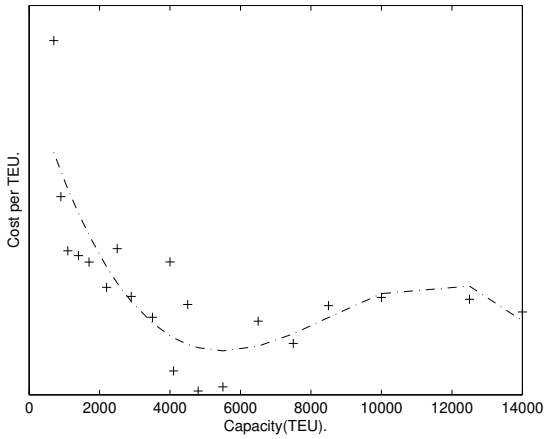


Figure 2.20 – The actual cost per TEU over the planning horizon for different vessel sizes. The plus signs are actual values and the dash-dot curve tries to fit the actual values in a polynomial of degree $n-1$ for n given values

a significant reduction in the use of fuel, therefore allowing more environmentally friendly service.

2.3.3.3 Phase II: Single-Ocean String Planning: Conservative Revision

Many LSCs are aware of the inefficiencies involved in their operations, or of the implications of making changes in their operational strategies such as changes to the network design, frequency settings, number of vessels on a service route, deployment strategies, etc. Nonetheless, they emphasize on smooth and gradual revisions rather than sudden and radical changes, which risk causing customer dissatisfaction and threatening the LSC's market share. Considering this, it seems that the best way to improve efficiency is through evaluating the system performance by generating scenarios based on making small and yet controllable changes in the network. In practice, this is carried out by revising the service network in a string-by-string manner.

During 2012-2014, there existed three main implications for such revisions (some of which are still valid): 1) Periodic seasonal changes in response to fluctuations in demands and the trade volume throughout a planning horizon. For example, the demand in the West for goods produced in the East dramatically increases just before Christmas and sharply drops down after that. The sequence of port calls and the vessel size deployed during peak season may not be optimal for low-demand seasons. There are in general three to four seasons across the year with the different patterns of demand. 2) Commitments to green logistics policies. Take the example of A.P. MollerMaersk A.S., the world's largest containership fleet operator, which had pledged to reduce its CO2 emissions by 20% by 2017 [Mat, 2010]. 3) Some unpredicted safety and security issues such as piracy and natural disasters can make such revisions inevitable. A recent example was the re-routing of vessels by the Cape of Good Hope, a South African port, to avoid piracy-ridden areas. This has been adopted by MAERSK Line on the route AE7 (see Figure 2.22) of an east-bound leg towards Asia, as well as a joint service of CMA-CGM and China Shipping Container Line. On AE7, the inbound voyage had been designed to pass through Malaga, the Suez Canal and the Gulf of Aden. However, due to the threat of piracy activities in the Gulf area, the string has been revised to skip some of the ports, which used to be called at the North Africa. Instead, it calls

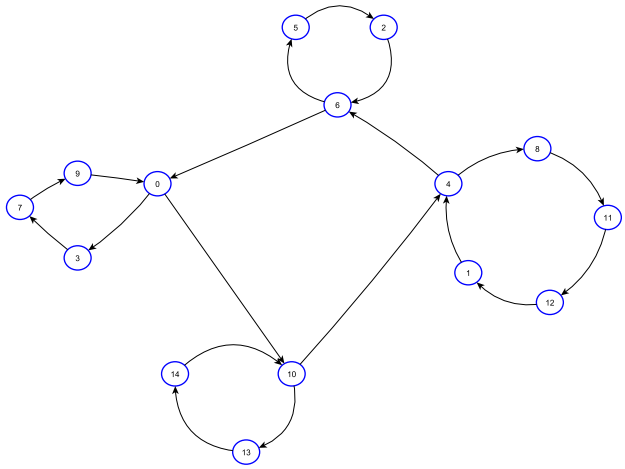


Figure 2.21 – A feasible solution to the $p - SPP$ with $p = 4$. The nodes '0', '4', '6' and '10' are main string ports of the associated feeder strings.

at the Cape of Good Hope, South Africa, on the way to Asia (see dashed linein Figure 2.22).

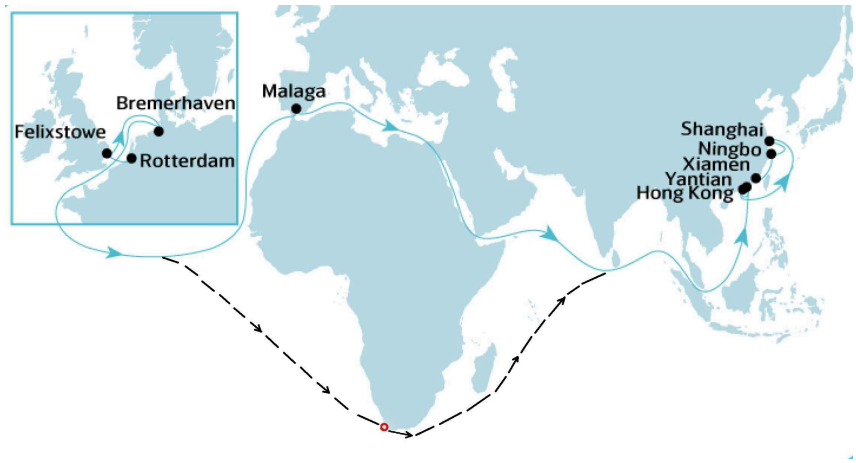
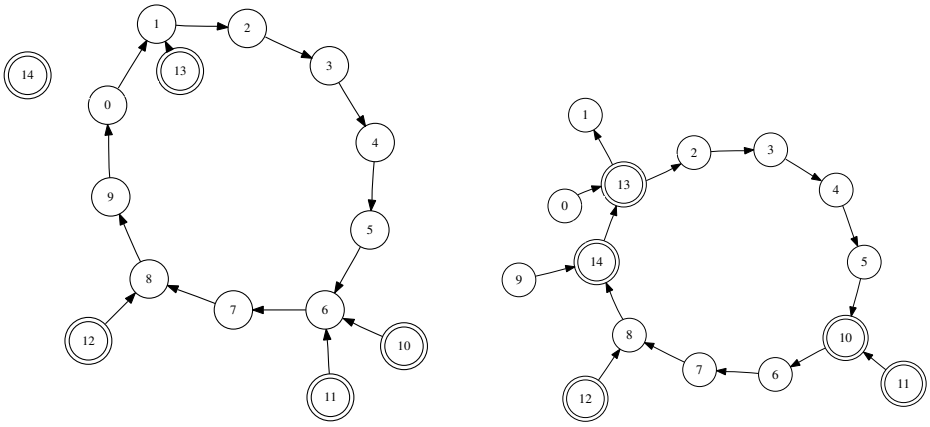


Figure 2.22 – Asia-Europe line AE7 of MAERSK (source: MaerskLine website, 2013).

We refer to this problem as SINGLE STRING PLANNING PROBLEM (SSPP) that can be formally presented as follows: *Given n, the total number of ports, a set of O-D demands between pairs of ports, associated O-D revenues, transportation costs for each leg of call, transshipment cost at every port, a finite set of different vessel classes, associated fixed deployment costs, minimum/maximum possible frequencies (as a multiple of weeks) and the possibility of negotiating with the customers on their cargo size, SSPP seeks a sequence of m port calls ($m \leq n$) such that: (i) the sequence of ports on the string defines a length within a lower and an upper bounds. This length will be an approximate*[5] *multiple of seven days, and is measured by the sailing time for a given speed (the particular LSC's stated preferred or economically preferable speed), (ii) each one of the remaining $n - m$ nodes not selected to be on the string is allocated to one and only one of the ports chosen along the string (with the cheapest transportation cost), (iii) the cargo size is assumed flexible in the sense that it can be fully accommodated, partially accepted*

[5]Because it can be adjusted by tuning the speed in the operational phase.



(a) The operating string before revision.

(b) The revised string.

Figure 2.23 – A network design of SSPP: The doubly circled ports (except no.14) in (a) are non-string ports. They might not be directly related to this string, or they are feeder ports, in which case they are allocated to (interact with) the string ports. In (b) some of them entered into the string and became string ports, and some string ports became feeder (spoke) ports, and left the string.

or totally rejected (based on profitability), (iv) the number (i.e. *frequency) and type* i.e. *of vessels on the string and each non-string leg are determined, and (v) finally, the overall profit (revenue minus costs) is being maximized.*

Figure 2.23 (a) depicts a typical network topology of such a problem for Figure 2.23 (b).

We proposed an efficient local search, which is composed of nine neighborhood structures for the problem and share some similarity with the adaptive variable neighborhood search methods. An inexpensive learning mechanism governs the choice of next neighborhood to be investigated based on the scores associate to them. This local search competes with the exact decomposition approach proposed by [Gelareh and Pisinger, 2011b], both in terms of quality of solution and computational time. We showed that whenever the exact method is capable of obtaining an optimal solution, our heuristic finds an optimal solution in much less computational time. Moreover, whenever the exact method terminates without reporting an optimal solution (perhaps with a solution of given quality), our heuristic finds significantly higher quality solutions in a small fraction of time needed by the exact method. Moreover, using extensive computational experiments we show that for significantly larger instances (real-life size), *e.g.* 50 ports, our heuristic converges in a slightly more than an hour of computational time, while the exact method is unable to tackle instances with 15 ports and larger.

A special property of this model is that the objective function has a behavior akin to the one presented Figure 2.24 making greedy algorithms producing efficient solutions for this problem and embedding multicommodity flow problems.

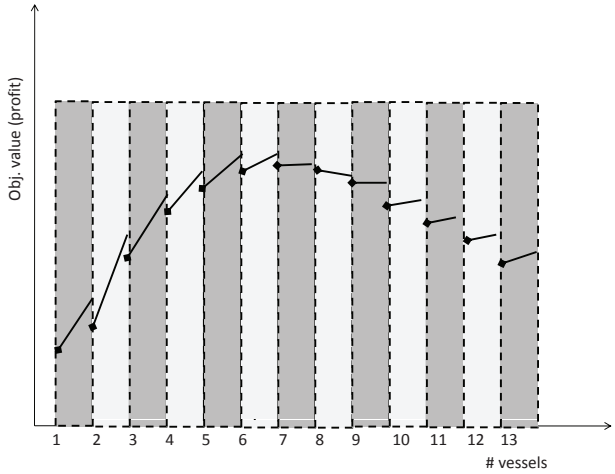


Figure 2.24 – Behavior of the objective function in SSPP: An increase in the number of deployed vessels incurs an additional cost, and the additional capacity made available is used to increase profit by accommodating more demands onboard. However, there is a turning point, where adding more vessels will decrease profit since the objective function and the fixed deployment cost start to have a negative effect on the profit. This occurs for various reasons such as a drop in the utilization of vessels.

2.3.3.4 Phase III: Graph Structure Similarity with Telecommunications

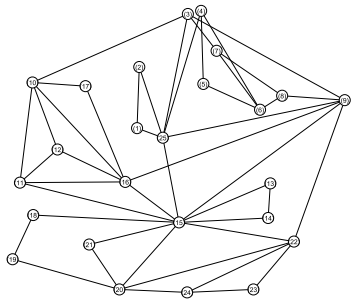
RING SPUR ASSIGNMENT PROBLEM (RSAP) introduced in [Carroll et al., 2011], arises in the design of next-generation networks (NGN) in telecommunications. This problem can be considered as a location-allocation problem. In this problem, every node of the network lies either on a ring among a set of bounded disjoint *local* (feeder) rings or is spurred by a single arc to another node on a local ring. A special ring, called *tertiary* (main) ring, interconnects the local rings. Figure 2.25 illustrate such a network structure.

This network structure is a generalized version of some of the structures we have seen previously and therefore sounded very attractive.

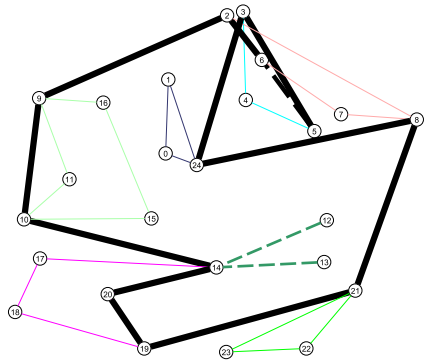
The goal is to design an economical fault-tolerant next-generation network for a given telecommunications operator. Such a resilient network is indeed a logical topology for an existing physical infrastructure —that is, we exploit the pre-installed capacities in the physical synchronous digital hierarchy (SDH) [Carroll et al., 2013]. This means that if a given node has only one incident edge, or if the residual capacity of a ring is insufficient, the node can only be a spur node connected with a single arc to another node on a local ring. Figure 2.25 (b) represents an optimal solution to the instance 'France' in Figure 2.25 (a) from SNDlib [Orlowski et al., 2007].

In [Monemi and Gelareh, 2017c], we proposed a new modeling approach to this problem. Our new integer programming model employs only $O(n^2)$ variables compared to the original $\mathcal{O}(n^3)$ and has a stronger LP relaxation. Several classes of valid inequalities and corresponding separation procedures are presented giving rise to an efficient branch-and-cut solution algorithm. We reported optimal solutions for all SNDLib instances including those that have not been previously solved to optimality.

This network structure contains almost all the elements required to model the global



(a) The original physical network with the existing installation.



(b) The optimal solution where the local ring bounds are set to 8 edges and two nodes 12 and 13 are spurred to local ring node 14.

Figure 2.25 – Illustration of the network of instance 'France' from SNDlib.

network design, including feeder services, main services and indirectly served ports (spurred arcs). We can exploit this to model our global liner shipping network design in the third phase. Our success in computational efficiency of our new modeling technique for the RSAP has put forward a new perspective for modeling and algorithmic framework of the global network design in liner shipping as follows.

2.3.3.5 Phase III: Network Design, Fleet Deployment and Empty Repositioning in Liner Shipping

The container trade imbalance on a container flow direction refers to the situation in which the number of export and import containers (even with respect to the type) differs significantly. While in developing countries the volume and even sometimes the value of import containerized freight is significantly more than the volume and value of export containerized freight, in some developed countries the imbalance is of a different nature. In the second group of economies, often the imbalance occurs because the import containers and the export containers are not of the same type, that is, one is composed of mainly 1-TEU (twenty-foot equivalent unit) containers and the other is more of 2-TEU (*i.e.* 1-FEU) containers.

A major part of this imbalance is due to the spatial distribution of production and consumption centres and the nature of imports and exports in different economies around the globe (see, [Wang, 2007]). Maritime shippers spend on average $100 billion per year on operating their container assets, of which around $16 billion is spent on repositioning empty containers [Rodrigue, 2016]. Moreover, according to the [UNCTAD, 2015], in 2015 the global ports' throughput was almost 2.2 times the whole containerized trade volume, implying a significant load of repositioning activities.

The East-West trade imbalance is continuing to expand, and the operation is becoming increasingly costly. Among the three major East-West trade routes (*i.e. Trans-Pacific*, *Trans-Atlantic* and *Europe-Asia*), in 2015 carriers operating between Asia and North America had to reposition 1.2 million TEUs more than they did in 2014. This is an indication of the increasing imbalance on the corresponding trade routes. On the other hand, the amount of empty repositioning has decreased by around 600,000 TEUs for the trade between Asia and Europe (including the Mediterranean region). However, still on the corresponding route(s), the to-

tal number of empty containers repositioned is as high as around 7.8 million TEUs [UNCTAD, 2015].

According to Drewry, this situation has been degrading in the last few years (see, [Waters, 2016] and Container Insight Weekly[6]).

In the literature the problems of network design and empty repositioning in liner shipping are often studied separately. What we refer to as a '*network design problem*' in this work, is the problem of designing from scratch a network (characterized by a set of nodes and a set of arcs incident to those nodes) and the corresponding service routes composed of those arcs (legs of calls) constituting the ship round trips. Our problem is not to choose routes only from among set of *a priori* existing and known ones.

In [Monemi and Gelareh, 2017a], we presented a generalization and the outcome of several years of our research and consultancy project carried out in liner shipping. In this work, we proposed an integrated modeling framework for the joint problems of network design, fleet deployment and empty repositioning in liner shipping. In our problem, the number of service routes and their design is an endogenous part of the problem.

The cost of a route is a set function mapping a subset of edges, vessel types and quantities to deploy, to the set of non-negative real numbers. Since such a cost structures cannot be accommodated in a compact formulation, our Benders reformulation-based modeling framework, integrates disjoint problems aiming at obtaining a solution to the integrated problem.

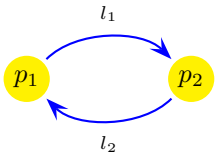
In this work, we look at the Benders approach as a tool for integrating separate optimization problems rather than decomposing an initial integrated holistic optimization problem. Our numerical experiments show that the method is very efficient in solving instances of this problem with respect to both problem size and computational time.

In liner shipping service networks, three main patterns may be observed on a service route: 1) *pendulum* segments (see Figure 2.26 (a)), which are in the form of direct calls between two major ports, 2) *butterfly* segments (see Figure 2.26 (b)), in which certain ports are called at twice, and 3) *cyclic* segments (see Figure 2.26 (c)), in which every port is visited exactly once on a route and which are composed of more than two ports. In practice, a route can be of a general form, composed of these essential components, as one can observe in Figure 2.27.

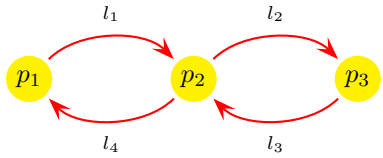
Designing a liner shipping network from scratch is a complex process. Here, neither the total number of routes in an optimal design nor the combination and number of segments of each category on every route are known in advance. However, in reality one can exploit the existing knowledge of real practice to preprocess and identify: 1) the ports that must/must not be served by a main route, 2) the ones that must not be served unless by feeder services, 3) the direct links that are unlikely to be established (*e.g.* a call of a medium/mega-sized vessel to Greenland or Iceland, a normal call to a port in Libya before heading towards a U.S. port or a port call to some of the forbidden destinations before calling at Beirut in Lebanon or Tartous in Syria), and 4) the ports that cannot be called at unless using certain vessel classes (*e.g.* due to the draught limit, port efficiency issues, etc.).

Here, we propose the first integrated modeling framework and scalable algorithmic approach that can fully (with a practically accepted level of details) characterize the structure of an optimal operational network for a liner service provider. It allows liners to analyse their

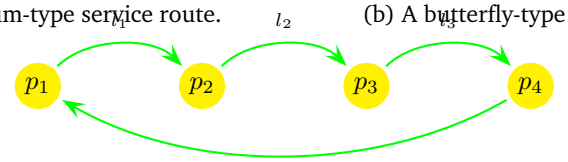
[6] www.ciw.drewry.co.uk



(a) A pendulum-type service route.

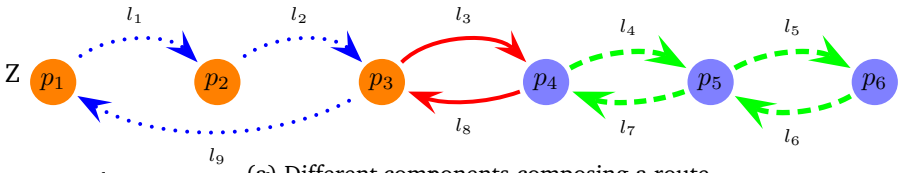


(b) A butterfly-type service route.

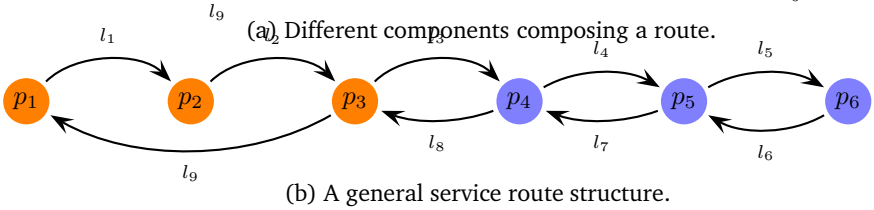


(c) A cyclic service route.

Figure 2.26 – The simple service route building blocks.



(a) Different components composing a route.



(b) A general service route structure.

Figure 2.27 – A general route structure and fundamental cycles.

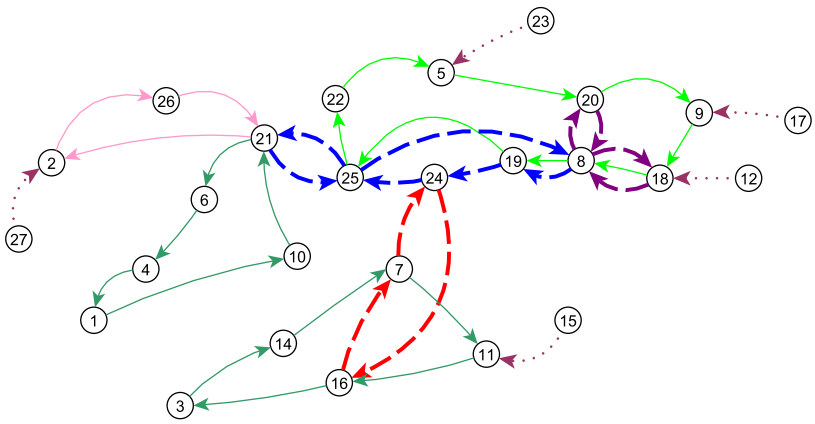


Figure 2.28 – An artificial example of a feasible solution network design. Here, the thick dashed arcs belong to the main routes (distinguished by colours) and the thin solid arcs belong to the feeder routes. The main route level network is a connected network. Every port along such a route is a main port where transshipment takes place; therefore, every such port must be on at least two routes (whether a feeder or the main route). The dotted arcs correspond to the allocation arcs for the isolated ports.

network under different scenarios (entire redesign or incremental and zonal redesign), such as fixing part of their network and analysing the remaining part. From the methodological point of view, it proposes a solution-method-driven modeling framework that can integrate separately designed models into a single optimization problem. More importantly, it extends the Benders decomposition to an exact method that can accommodate experts' knowledge.

A port that lies on at least one service route is referred to as a *route port*. Every port either lies on at least one service route or it is an *isolated port* that is allocated to another port via which the origin-destination demands are transported (*e.g.* ports #12, #15, #17, #23 and #27 in Figure 2.28). Such an allocation is represented by a dotted arc from the isolated port towards one single route port (allocation arc). The transportation service between an isolated port and a route port is considered as being outsourced and is not subject to any fleet allocation.

We define a *risk factor* that is a (monetary equivalent) value associated with every potential arc $(i, j) \in \mathcal{L}$, indicating the degree of reluctance (or emphasis) of experts (management) to include certain legs of calls in the service network —regardless of the service route. This reluctance may stem from several sources, including political, strategic and business-related ones or any other confidential and sensitive context. Moreover, a penalty cost is associated with the allocation of an isolated port to every other port. This cost structure is a quantification of qualitative measures associated with the legs and is extracted from experts' knowledge. A transit time is associated with every arc (leg or allocation), which represents the expected transit time on that leg of calls in the current market.

There are three kinds of service route. 1) The main service routes can be no longer than α_1 weeks. Each port on such a route is a main port and must be served by at least two service routes (at least one of them must be a main route). 2) The feeder services are no longer than $\alpha_2 < \alpha_1$ weeks' transit time.[7] 3) The outsourced feeder services connect *isolated* ports to the route ports. As mentioned previously, the demands and supplies of such outsourced

[7]In practice, α_1 is often considered as 12 weeks while α_2 is known to be often around 3 weeks.

services are delivered by a second company without having to know, ourselves, the details of that operation.

An LSC operates a heterogeneous fleet of vessels from $|\mathcal{V}|$ distinct containership classes. The cost of operating a route is a cost associated with the string as a set (of legs and their political/economic characteristics and vessels with their cost structures) rather than individual elements. This cost is a function of the transit time of the legs in the set, the port handling cost per unit of container, varying insurance regimes on different legs of calls, security considerations, various regulations of operation in different territorial waters (*e.g.* speeds limits) that may impose some route-specific bunker consumption patterns and port calls, bridge and canal fees, to name a few. Moreover, some experts' knowledge (political, strategic and economic factors) interfere when the operational cost of a route is being calculated. However, in the latter case, often no closed-form formulation is known for most of these factors.

Hence, the operational cost of a route $r \in 2^{\mathcal{L}}$ operating a set of vessels of class $v \in \mathcal{V}$ (to maintain a weekly frequency) can be defined as:

$$C_r^v : (2^{\mathcal{L}}, v) \to \mathbb{R} \tag{2.1}$$

where $\mathcal{L}$ is the set of potential legs and $2^{\mathcal{L}}$ represents its power set, $\wp(\mathcal{L})$. Moreover, our empirical studies show that for every $X \in \wp(\mathcal{L}), x_1, x_2 \in \mathcal{L}/\ X$ we have $C_r^v(X \cup \{x_1\}) + C_r^v(X \cup \{x_2\}) \geq C_r^v(X \cup \{x_1, x_2\}) + C_r^v(X)$. Therefore, it behaves akin to a submodular function and as a consequence it has all the properties of a convex function.

In addition to the operational cost of route r served by vessel $v \in \mathcal{V}$, C_r^v, the container handling cost (including loading, discharging and transshipment for both empty and laden containers) is another component of the string operating cost. While the origins and destinations of demands are inputs (*i.e.* the exogenous part) of the problem and do not include any flexibility, the choice of transshipment port and the number of transshipments along every O-D path is an endogenous part of the problem. As a result, one may expect that the operators may always find a port p where the transshipment cost is cheaper than the loading plus discharging cost.

In [Monemi and Gelareh, 2017a], we assumed that the liner company owns the entire fleet operating on its service routes and that charter costs and so on do not apply here. We further assumed that the LSC is allowed to fulfil any portion of an O-D demand. However, the liner currently has enough capacity to transport its current demand volume.

As it can be observed in Figure 2.28, every service route (distinguished by colour) is composed of a combination of the building blocks shown in Figure 2.26, namely pendulum, butterfly and cyclic (sub-)routes. The service routes are constructed by chaining together the building blocks based on some qualitative criteria. This relies chiefly on the experts' knowledge, taking into account some political/economic considerations.

The problem can be described formally as in the following: *Given all the aforementioned assumptions and information, one seeks to determine strings by respecting the round-trip transit times, identifying isolated ports, the routing and transshipment of laden containers and the repositioning of empty containers. The objective is to maximize the profit that accounts for the difference between the revenue generated by the volume of transported demands and the cost of operating strings as well as the cost of the risks associated with each arc. The market transit time of routes must be multiples of weeks to maintain a weekly frequency.*

Given that the cost structure for routes is a set function, a polynomial formulation of this problem seems to be non-trivial. Therefore, instead of proposing a compact formulation, our modeling framework relies on a Benders reformulation of the problem. The master problem (MP) is a route generation problem (RGP) with the aim of proposing network structures (in the form of the components shown in Figure 2.26, while the subproblem (SP) solves a fleet deployment and flow routing problem (FDFRP).

The Benders decomposition offers great flexibility in modeling such kinds of integrated problems with separate structures by allowing an efficient exchange of information between the MP and the SP(s) through parameterizing the SP with realized variables of the MP. Here, in this problem the solution to the MP, rather than being a complete description of routes, is a set of different feasible components (butterfly, pendulum and cycles). The experts' knowledge that plays a crucial role here is a database of exactly 816 rules, which are mostly confidential, indicating several different instance-based and generic rules, such as the infeasibility of some sequential calls, the implications of certain sequences of calls due to strategic, business, cargo type and several other criteria. Among such rules, we also have the ones that try to combine components and obtain better approximation of multiple-week sailing times. Some such rules, in fact, even help to preprocess and fix quite a substantial part of the network or other elements of the service.

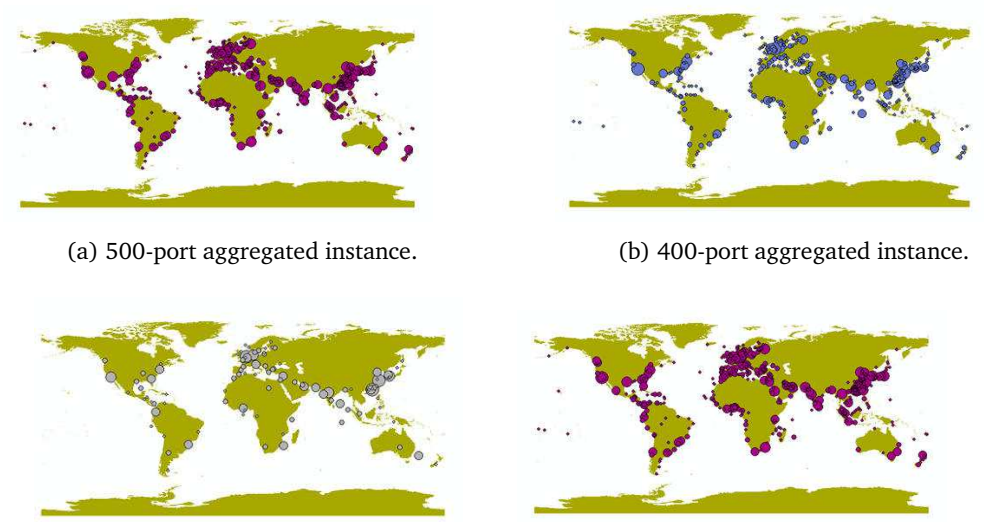
Our main instance is a network composed of around 830 ports (see Figure 2.17) that are directly or indirectly served by our liner shipping company. While the demand matrix for such an instance is very sparse, we have serious difficulties in solving the MP for such a huge number of variables. Therefore, we resort to some kinds of aggregation (akin to the one proposed by [Ernst and Krishnamoorthy, 1996]) to generate smaller instances. Examples of such smaller instances resulting from such aggregations are depicted in Figure 2.29.

We have identified several valid inequalities, efficient separation routines, branching rules and variable fixing techniques to propose a very efficient *branch, Benders and cut* method capable of solving to optimality some instances up to 100 ports and in a very reasonable time. For 105 to 200 nodes, solutions with an average quality of less than 5 percent have been achieved within 3 hours of computation. Further details can be found in [Monemi and Gelareh, 2017a].

2.3.3.6 Phase IV: Coopetition in Liner Shipping Network Design

Co-opetition (simultaneous pursuit of collaboration and competition) is a neologism coined to describe cooperative competition. In this kind of competition, players cooperate by exchange of information, sharing infrastructure and/or facilities, etc. in order to generate additional market for the collaboration as a whole. Simultaneously, the operators compete to increase their own share of the additionally generated market. Ideally, mechanism must be designed in such a way that stability of the system is not harmed by one of the operators trying to do better by considering playing unilaterally and stepping out of the '*alliance*'. Furthermore, the effect of cannibalization should be minimized if both operators are subsidiaries of the same company.

The co-opetition combines the advantages of both cooperation [Smith et al., 1992] and competition [Dyer and Singh, 1998] for a given company allowing it to increase its profit and affect its surrounding environment. Several fields in management research benefit from the co-opetition strategies (*e.g.* strategic management, organizational studies and experimental economics, see [Brandenburger and Nalebuff, 2011, Brandenburger and Nalebuff, 1996, Yami et al., 2010]).



(a) 500-port aggregated instance.

(b) 400-port aggregated instance.

(c) 200-port aggregated instance.

(d) 100-port aggregated instance.

Figure 2.29 – Some of the smaller instances generated by aggregation of the 830-port instance.

In [Gelareh et al., 2017a], we considered a short term collaboration among a very small number of operators. The objective is providing service to a very limited number of additional O-D demands (spot cargos that cannot be accommodated within the current service networks) or among a set of players over a longer horizon and a wider geographical zone, on a regular basis. In the earlier case, this is usually achieved by outsourcing the transport service from a competitor to carry out the mission while in the latter case we often refer to the term '*alliance*' composed of '*allies*' to describe the structure. On the one hand, the additionally generated market share is absorbed and on the other hand the partners can improve utilization of their fleets of transporters to better exploit economies of scale. Quite a few examples of the strategic alliances exist in airlines (*e.g.* Star alliance with allies in five continents), liner shipping (recently launched P3 Alliance, Grand Alliance, New World Alliance etc.) and railway-airline (*e.g.* Rail&Fly, an alliance between the DBahn and several airlines from different continents, TGVair, an alliance between the French railway company SNCF and some airlines etc.).

There are two LSCs denoted by $\mathcal{A}$ and $\mathcal{B}$ of the same mode of transport operating in different regions (perhaps with minimal or negligible interconnections). These two LSCs are not in a direct competition and/or collaboration as the local regulations do not allow one to operate on the entire regional network of another one[8]. The set of clients that can be potentially served by an LSC o is represented by $\mathcal{N}_o$. An LSC $o \in \mathcal{O} = \{\mathcal{A}, \mathcal{B}\}$ operates on a hub-and-spoke structure $\mathcal{N}_o = \mathcal{N}_o^H \cup \mathcal{N}_o^S$, where $\mathcal{N}_o^H$ is the set of hub nodes of operator o and $\mathcal{N}_o^S$ represents the set of spoke nodes of operator o. Here, every spoke in $\mathcal{N}_o^S$ is allocated to one or more hub nodes in the set of hub node $\mathcal{N}_o^H$ (see Figure 2.30).

In such a network, for every LSC $o \in \mathcal{O}$, the O-D flows chosen to be served will follow a path passing through at least one element of the hub-level network. For a given LSC, once

[8]For example as a result of Convention on Internal Civil Aviation –Chicago convention– or the shipping regulation in the territorial waters of some countries mainly in Asia region that make it, to a large extent, reserved for domestic players. Sometimes for the same operator, only a part of its fleet complying with certain regulations concerning flagging, maintenance history and crew background etc. is authorized to operate in certain regions, resulting in a disconnectedness between the networks over which its fleet is operating.

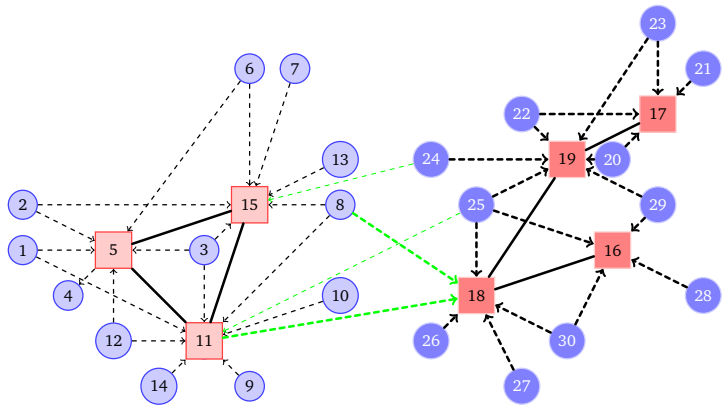


Figure 2.30 – An example of a Hub-and-Spoke co-opetition network. The rectangular objects represent hub nodes and the circles represent spoke nodes. The solid lines represent the hub-level edges and the dashed lines are the spoke edges connecting spoke nodes to hub nodes. Note that there is no direct connection between two spoke nodes. The lighter left-hand side nodes belong to the first operator and the darker right-hand side nodes belong to the second operator.

an O-D flow leaves its origin and arrives to the hub-level network, it traverses the hub-level network either up until the destination hub node or a hub node where the destination spoke node is allocated to it. Therefore, the hub-level network is a connected graph. However, the joint hub-level network (union of the hub-level networks of LSCs) is not initially a connected network and is composed of exactly two components. In other words, the LSCs do not share any hub node/edge (see Figure 2.31).

The LSCs' networks may still share some nodes. As shown in Figure 2.30, a spoke node in one LSC's network can be also a spoke in another LSC's network and therefore allocated to one or more hub nodes in each one of the two (see nodes #8, #24 and #25). Such allocations to two different networks are not to diversify the market for the same product, rather this is about different products exclusively supplied by (or demanded from) one of the networks. Furthermore, an LSC may use a node as a hub node while the other LSC considers it as a spoke node (see node #11, which is a spoke node of the right-hand side LSC), yet, the edge $11 - 18$ is not recognized as a hub edge because none of the two LSCs recognizes the both end-points as hub nodes.

In a competitive environment wherein LSCs $\mathcal{A}$ and $\mathcal{B}$ are operating and competing to occupy more capacity from the jointly established service for their clients in each other's networks, a *service level* (a so-called '*market transit time*' in this context) plays the key role in allocation of market shares to an LSC. In an application such as long-haul liner shipping, as a rule of thumb, if one LSC cannot provide a transit time of at most γ percent above the direct point-to-point transit time (the usual market transit time that other players can offer for the same O-D pair) then it certainly cannot absorb any part of the market.

We call a given O-D demand *captured*, if it is an internal demand of a given operator and is already served before co-opetition being launched. The flows to be captured from *non-captured* O-D pairs are unsplittable.

An LSC is not authorized to capture O-D demands of the original network of another LSC. For an LSC, the new market includes only those demands whose origins were in its

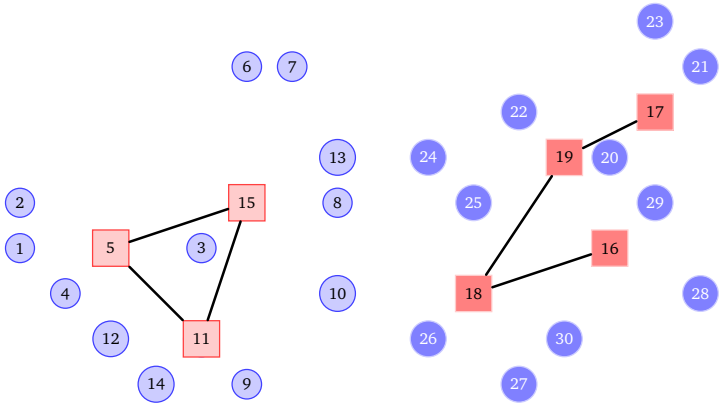


Figure 2.31 – In the initial configuration, no hub edge connects any pair of hub nodes of different LSPs.

own original network and their destinations were in the original network of the other LSC (and vice versa). As a consequence, the competition can only be realized on the collaboratively established edges (between different LSCs). It must be noted that in a given feasible solution, even if the collaboration level of an operator is zero, it can still have a positive competition level on those edges because even if investment for installing hub edges is not profitable for it, still the fact that it allows other to gain market on its territory must have some rewards for it.

The problem is described as follows: *Every node in the network of LSC $\mathcal{A}$ can potentially be a client for the LSC $\mathcal{B}$ and vice versa. We seek a unified hub-level network, which is a connected graph and in which every LSC can potentially gain more if operating on the new unified system compared to its own initial network. That is, by possibly restructuring its own network composed of hub nodes, spoke nodes and their allocations, the total revenue is at least as good as before, for every operator. We assume that all the existing infrastructure of every LSC can be still operational in the unified network. As a result, the O-D transit times are never increased although may even be reduced*[9]*. Such reduced transit times on the one hand can help in capturing additional internal demand market and on the other hand the reduced transit times for internal demands may be interpreted as lower transportation costs if the same shipping setting is kept.*

Any new hub edge connecting hub nodes of different LSCs is '*collaboratively installed and competitively exploited*'. A normalized factor/level of cooperations influences the contribution of each LSC in the fixed cost of installation. Another normalized factor/level of competition determines the type of transporter (*i.e.* , capacity and possibly other features) deployed on the jointly installed hub edges (a larger transporter that offers better economies of scale competes better on both the transportation cost and capacity).

For every LSC, the cost of collaboration, which accounts for the contribution in installing new hub edges and hub nodes, has a quadratic form (if one does not contribute the other one contributes by 100% and partial contributions by both parties reduce the overall cost of a jointly installed service), and the competition cost that is resulted by deploying a given transporter, with a given design speed and capacity, has a linear form. The objective is to

[9]This can occur because the additional profit generated by the increased market share of inter-network demands can be invested in installing new hub nodes and edges for every operator and as a result new paths with shorter transit times can be identified.

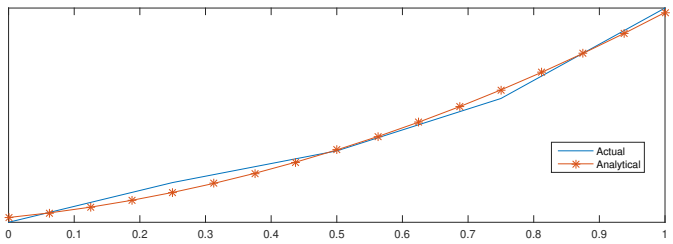


Figure 2.32 – The real form of a cooperation cost function is shown in solid (blue) line. The quadratic approximation of the real curve is plotted in (red) line-star style.

maximize their profits that account for the revenue after deducting hub facility installation, transportation, competition and cooperation costs.

The co-opetition cost for the operator o has the following form [De Ngo and Okura, 2008]:

$$z_o = (r - c)y\frac{x_o}{x_A + x_B} - k_x x_o - k_y y_o^2, \tag{2.2}$$

where r is the revenue, c is the cost, x_o is the competitive effort level of operator o, y is the decision to be made and $k_x x_o$ ($k_y y_o^2$) represents the cost of expending competitive (cooperative) efforts, respectively. Our empirical studies and data mining on a large dataset from our industrial partners reveal that such a function for the operator o can be approximated by the following quadratic form [De Ngo and Okura, 2008] (see Figure 2.32):

$$f_{k,l}^{+\,o}(z_{kl}^{+}) = \frac{4}{7} I_{kl}^{o} (z_{kl}^{+\,o})^2 + \frac{68}{175} I_{kl}^{o} z_{kl}^{+\,o}. \tag{2.3}$$

This is the cost incurred based on the level of cooperation between two liner service providers. In the absence of any kind of cooperation, no cost is incurred while a full cooperation (being the only investor in establishing connection) incurs the full cost of installation.

According to [Notteboom and Carriou, 2009], in liner shipping industry, the total fuel consumption at sea for the main engine m in grams/day d and at a given design speed s_0 can be estimated as:

$$FC_{md}(s_0) = 3.775 \times e^{1.996} \times TEU^{1.013}. \tag{2.4}$$

In our work, the competition cost is composed of two parts. The first part is interpreted as the impact of the increase/decrease in vessel speed from the initial economic design speed s_0 (which corresponds to a coefficient α) to a speed s [Stopford, 2009], and the second part is the cost incurred by deploying the vessel for claiming more slots from the whole capacity of the jointly-operated edges. When dealing with containerships, the fuel consumption at the speed s with design speed s_0, can be calculated using the following cubic function:

$$FC_{md}^{v}(s) = FC_{md}(s_0)\left(\frac{s}{s_0}\right)^{3.3}, \qquad \forall v \in \mathcal{V}. \tag{2.5}$$

However, as one can see in Figure 2.33, on a given interval, this function can be approximated by a straight line —more precise for the smaller ones. By substitution:

$$FC_{md}^{v}(s) = a_v\, s + b_v, \qquad \forall v \in \mathcal{V}. \tag{2.6}$$

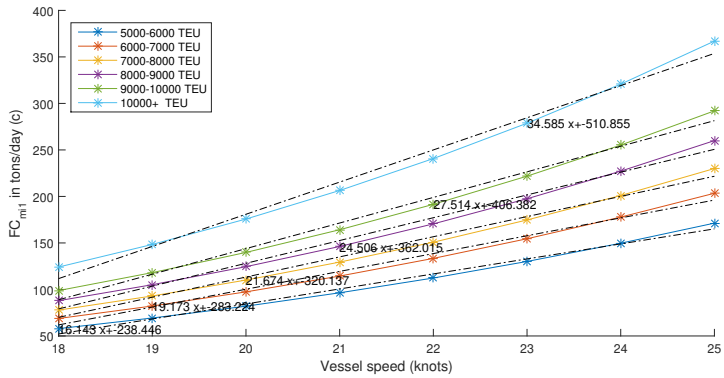


Figure 2.33 – Fuel consumption as a function of vessel speed for every one of the six vessel classes. For each class, the dashed (black) line represent linear approximations of the corresponding real (colored) curve. Within the practical sailing speed interval, the approximation is *almost* precise.

The corresponding a_v and b_v are reported in Figure 2.33. However, to avoid further nonlinearity, we restrict ourselves to a few possible values (*stars* in Figure 2.33).

Let FC^{vso} be the cost of operating vessel v at speed s for operator o, the first part of competition cost follows:

$$FC_{kl}^{sv} = FC_{md}^{v}(s)\eta_{kl}^{vso}\frac{D_{kl}}{24s}, \qquad \forall (k,l) \in \mathcal{E}, s \in \mathcal{S}, v \in \mathcal{V}. \tag{2.7}$$

If slow-steaming strategy is adopted, it reduces the transportation cost while if a strategy based on increasing speed on the given edge is adopted allowing the total transit time of an O-D pair be below $(1+\gamma)T_{ij}^{o}$, the transportation cost may increase but at the same time the operator can compete for capturing market share.

The competition cost function for operator o can be approximated by:

$$f_{k,l}^{-\,o}(z_{kl}^{-}) = \sum_{v\in\mathcal{V},s\in\mathcal{S}} \frac{FC_{kl}^{sv}}{FC_{kl}^{s_0\,v}} z_{kl}^{-\,o}, \qquad \forall (k,l) \in \mathcal{E}. \tag{2.8}$$

In [Gelareh et al., 2017a], we proposed one of the first co-opetitive network design and fleet deployment problems, which is formulated as a mono-level and mono-objective mathematical programming formulation. The model is a generic one that we customized it to take into account features from the liner shipping industry. The resulting model is a large scale and very intractable optimization problem even for very small size instances. To solve this model, we proposed a matheuristic solution algorithm integrating Lagrangian relaxation within a local search algorithm that can be used to obtain good solutions and acceptable from the industrial point of view.

2.3.4 Summary of Research Activities

In what concerns liner shipping operations, the following activities have been carried out:

- One completed PhD thesis (N. Belayachi) and one ongoing,

- Six peer-reviewed ABS[10]-ranked international journal articles ([Monemi and Gelareh, 2017a], [Gelareh et al., 2017a], [Gelareh et al., 2013d], [Gelareh et al., 2013a], [Gelareh and Pisinger, 2011a], [Gelareh et al., 2010], [Gelareh and Meng, 2017] and joint works with the PhD students. [Belayachi et al., 2018], [Wang et al., 2009],
- Several peer-review international conference papers both jointly with the students and with other fellow colleagues ([Gelareh et al., 2017b], [Gelareh et al., 2015a], [Danach et al., 2015c], [Gelareh and Monemi, 2017], [Gelareh and Meng, 2009], [Semet and Gelareh, 2015]), [Yachba et al., 2014], [Gelareh, 2008a], [Monemi and Gelareh,], [Danach et al., 2016], [Belayachi et al., 2015], [Gelareh et al., 2016b], [Danach et al., 2015a], [Gelareh et al., 2015c], [Danach et al., 2014a], [Gelareh et al., 2014], [Gelareh et al., 2011], [Gelareh, 2010], [Gelareh and Pisinger, 2010a] and [Gelareh and Pisinger, 2010b].

2.4 Beyond the Liner Shipping and Network Design

Apart from the main focus, we have been also active in identifying the transferability and potential areas where we can contribute given the experiences we obtained in modeling and algorithmic development in the main focus area. These topics often stem from the consultancy projects or regional projects jointly carried out in collaboration with other universities in the region. Here we only cite the peer-reviewed publications.

2.4.1 Truckdock Assignment Problem with Operational Time Constraints

Crossdocks play a key role in modern distribution systems. They are logistic terminals where deliveries are unloaded from inbound trucks, sorted and moved from one dock to another –within the crossdock– until they are finally loaded on the outbound trucks towards the next destination along the logistic chain. Crossdocks are often used to perform rapid transshipment activities and usually do not carry out any further processing of the shipments (see Figure 2.34).

An important problem in a crossdock is the dock assignment of inbound and outbound trucks, given the characteristics of crossdock (such as layout, installations, resources, capacity etc.) and those of clients (such as time windows within which the trucks are present at crossdock, origin-destination volumes of flow etc.). In [Gelareh et al., 2015d], given the time windows defined by the arrival and the departure times of every truck (as well as capacity of the crossdock), we aim at finding an optimal assignment of the trucks to the docks in such a way that the number of deliveries being processed is maximized. A delivery from an inbound truck that has not succeeded to leave the crossdock using an outbound truck in the same day, imposes some overnight holding costs at the crossdock until being delivered to its destination in the next call of the outbound truck (which is usually the next day). Every inbound truck usually has shipments to several different destinations. Whether an inbound truck will be able to deliver to an outbound truck via crossdock depends on: 1) feasibility of time windows (*i.e.* the outbound truck does not leave before the inbound arrives), 2) the arrival time of incoming truck plus the dock-to-dock transfer time within the crossdock, which should not exceed the departure time of the outbound truck, and 3) the available capacity at the crossdock during the visit time window of the inbound trucks.

In [Gelareh et al., 2015d], we proposed a new integer programming model for this problem. The dimension of the polytope associated with the proposed model is identified by introducing a systematic way of generating linearly independent feasible solutions. Several classes of valid inequalities are also introduced, some of which are proved to be facet-

[10] Association of Business Schools

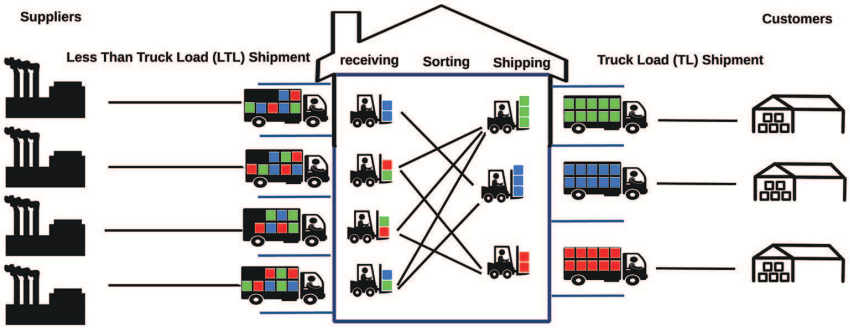


Figure 2.34 – Crossdocking in a distribution network.

defining. Then, exact separation algorithms are described for separating cuts for classes with exponential number of constraints, and an efficient branch-and-cut algorithm solving real-life size instances in a reasonable time is provided. In most cases, the optimal solution is identified at the root node without requiring any further branching.

2.4.2 Logistics in the Energy Sector: Workover Rig Problem

Many land (onshore) oil fields are operating several wells, which are distributed across geographically wide region (see Figure 2.35). Occasionally, failures happen on these wells, requiring an intervention to return to their original condition. Such operation normally includes substituting the production equipments (cleaning) or stimulating the reservoir itself (stimulation), to name a few. Those interventions require the use of *workover* rigs, big structures that can be dismounted, transported and mounted from one well to another, providing safety and accuracy conditions to the intervention. Renting workover rigs comes at a great cost, thus having them at standby availability is expensive. Moreover, there is a compatibility constraints between a workover rig and the well to be served, based on different indices.

In [Monemi et al., 2015] we proposed a new mathematical model for the problem of onshore interventions using workover rigs in order to minimize production loss associated with the wells awaiting service. We looked at this problem as a parallel heterogenous machine scheduling problem. We proposed a new mixed integer linear programming model for this problem that is an arc-time-indexed formulation. We proposed a heuristic selection type hyper-heuristic algorithm, which is guided by a learning mechanism resulting in a clever choice of moves in the space of heuristics that are applied to solve the problem. The output is then used to warm start a branch, price and cut algorithm.

Our numerical experiments are conducted on instances of a case study of Petrobras, the Brazilian National Petroleum Corporation. The computational experiments proved efficiency of our hyper-heuristic in searching the right part of the search space using the right alternation among different heuristics and confirms the high quality of solutions it obtained.

2.4.3 Summary of Research Activities

Several projects have been carried out some of which resulted in publications and supervision activities as in the following:

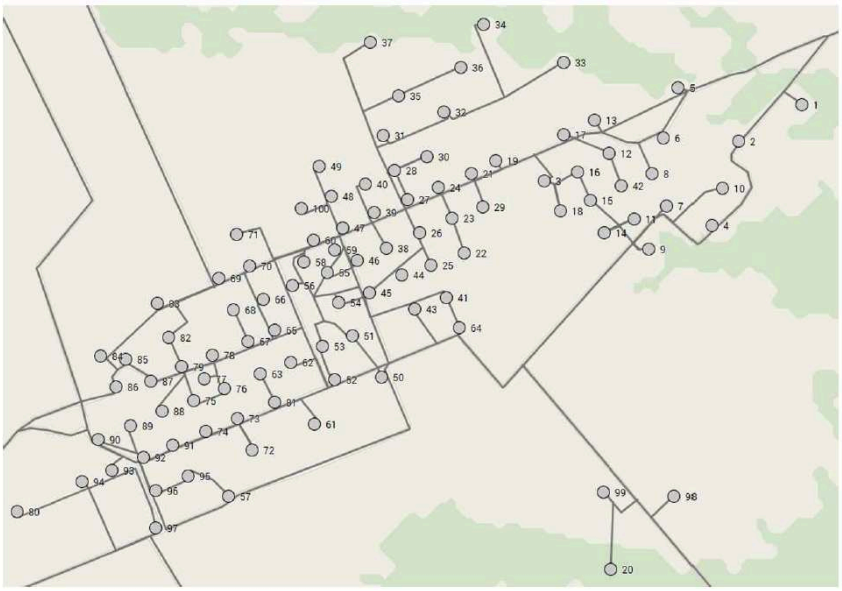


Figure 2.35 – The wells are uniformly distributed within a given geographical zone.

- One completed thesis (K. Danach) and one ongoing (O. Kemmar)
- Crossdocking: Two ABS-ranked peer-reviewed international journal articles ([Gelareh et al., 2015d] and [Gelareh et al., 2018]) and a conference paper ([Gelareh et al., 2013c]),
- Telecommunications: A peer-reviewed ABS-ranked international journal article ([Monemi and Gelareh, 2017c]) and a few peer-reviewed conference papers ([Monemi and Gelareh, 2017b], [Monemi and Gelareh, 2017d] and [Gelareh et al., 2016a]),
- Petroleum Logistics: A peer-reviewed ABS-ranked international journal article with the PhD student ([Monemi et al., 2015]) and a peer-reviewed conference paper jointly with the student and fellow colleagues ([Gelareh et al., 2015b], [Monemi et al., 2016] and [Danach et al., 2014c]).

General Conclusion and Perspectives

2.5 Review of Activities

Since 2008, our research activities have been centered around the combinatorial optimization problems arising in liner shipping industry. A close collaboration with the major players in industry has been maintained both on the port side and on the shipping side. Recently, a strategic partnership has been established with a couple of private investors in healthcare facilities who provide both, facilities and facility management services within the healthcare sector. The strength of research both in logistics and healthcare at LCOMS research lab of Université de Lorraine supports the prerequisites to address inefficiencies at different levels from facility location within mega-structures, layout design and resource allocation, scheduling and daily logistics at such facilities managed by these companies. A close research and consultancy collaboration with members of LCOMS is intended in this framework.

2.5.1 Port Side

We first addressed concerns of port operators, which raised when the first mega-vessels started to be deployed by major liner service providers. In [Gelareh and Meng, 2017], which was indeed a *pioneering* work in the literature, we identified the optimal deployment scenario for liner shipping companies, to determine the type of vessels they would use to call certain port of different strings. This problem was also studied in uncertain environment as in [Wang et al., 2009] using a chance constraint model and in [Gelareh and Meng, 2009] from a possibilistic theory point of view. Later, in [Monemi et al., 2009], we carried out a simulation study of the impact under the optimal deployment scenario we identified in [Gelareh and Meng, 2017].

This research aimed to inform local authorities and port operators of the impact of the upcoming changes and the necessity to plan for their mid-term and long-term investment in order to maintain a quality service and minimize the turnaround time of vessels. They also provided the liner shipping companies with a vision on their expectations of turnaround time and efficiency in vessel handling in the new setting.

We later were introduced to another problem and wherein the number of 40-ft containers were going up and smaller ports with confined spaces needed to acquire and deploy 40-ft containers transporters in such confined spaces causing them additional inefficiency in traffic management (*e.g.* deadlocks, etc). In the framework of InTraDE Interreg IVB, we concentrated on the small ports of North West Europe for which any scenario of expansion seems unrealistic given their geographical location, physical characteristics and neighborhood. With the new technology of IAV being developed, we have studied the possibility of maintaing/improving efficiency of port operations in presence of IAVs (20-ft transporters

that can pair up and transport 40-ft containers and split again upon completion of tasks).

2.5.2 Liner Shipping Industry

We have been then attracted by a few interrelated new major problems that were appearing in the liner shipping industry: fleet deployment, network design and empty repositioning[11].

Fleet deployment problem could be studied in tactical-operational level by taking into account some low-level details. However, a higher level and aggregated description of it must also be studied together with the network design problem as these two problems are highly inter-connected. Yet, such a coupling often results in models that are very intractable and often even very specialized and tailored solution methods fail to solve realistic size instances.

Since 2009, we have been working on models for joint problems of network design and fleet deployment for regional feeder services in smaller scale. We have gradually improved the computational performance of algorithms (with a particular emphasis on the Benders-like decomposition techniques) and identified the pros and cons of different techniques (primal and dual decomposition techniques). Over the time we have enlarged our problem description and have integrated more and more realistic features in our mathematical models. From one single feeder string, we moved to the multiple feeders served by multiple ocean-going service rotation and from dual decomposition methods (Lagrangian-like methods) to primal decomposition (Benders-like methods).

Over this period, we have been introduced to several other problems, some of which shared some similar network structures or enlightened new ways of modeling, resulting in more compact models and higher computational efficiency. Over the time, we have reached to a more mature understanding of decomposition techniques, which led to the BENMIP project (an Open Source Automated Generic Benders decomposition solver). Having found similar network structures in other application areas we pushed the computational efficiency for those problem (Ring Spur Assignment Problem [Monemi and Gelareh, 2017c]) by a combination of novel modeling technique and better polyhedral information (valid inequalities) and brought those developments back to our main focus area.

This has led us to novel modeling technique and approach. In this approach, we looked at Benders decomposition method as a modeling tool to cleverly link two or more interrelated problems rather than a solution algorithm to decompose an existing model to a master and a subproblem. This is in particular very important when each of the separate problems can be solved efficiently but the joint problem remains intractable.

Such a novel modeling technique introduced a very high computatonal efficiency that allowed us to incorporate the problem of empty repositioning into the combined problem of network design and fleet deployment. In 2010, we started working in this area when our best algorithms were not able to solve any network size with more than 15-20 nodes (see [Reinhardt and Pisinger, 2012], [Gelareh et al., 2010], [Gelareh and Pisinger, 2011a] and [Gelareh et al., 2011] etc.) and reached to a modeling framework wherein we can solve an optimization problem of more realistic problem description (fleet deployment, network design and empty repositioning) [Monemi and Gelareh, 2017a] in a global scale for 200 nodes in almost three hours and achieving solutions with quality of in average 3 percent deviation from optimality.

[11] The empty repositioning makes amount 100 billion dollar of annual operations world-wide

2.5.3 Other Projects

We have carried out several research (and development) as well as consultancy projects, some of which opened new avenues in our research. This includes a project in workover rig problem ([Monemi et al., 2015]) as a part of PhD dissertation of Kassem Danach. Another case, was the problem of truckdock assignment in crossdocks which has resulted in [Gelareh et al., 2015d] and [Gelareh et al., 2018].

There are currently other PhD co-supervision in collaboration with some North African LNG shipping companies, which is the context of one of our future articles. There are also other ongoing submissions that are resulted from other consultancy projects and are expected to appear.

2.6 Research Agenda and Perspective

The agenda and perspective includes two parts. The first part builds on the top of the ongoing activities and our investments over the last decade and the second part includes the collaborative research agenda within the LCOMS. The latter comes first and followed by the former.

2.6.1 Joint Plan of Research within LCOMS

The Industry 4.0 (and consequently Mobility 4.0) or computerization of manufacturing (in a broader sense as a system that includes a collection of interactive processes such as in hospitals and healthcare systems) is the current trend of automation and data exchange in manufacturing technologies. Industry 4.0 relies on the Internet of Things (IoT), cyber-physical systems, and cloud computing that collaborate to offer decentralized decision making. A massive flow of data and information is involved while efficiency of increasingly more complex supply chains must be guaranteed to ensure the competitiveness and sustainability of supply chains. *Data* (data modeling and knowledge extraction), *Modeling* (mathematical and simulation models of activities or processes) and *Computation* (efficiency in identify optimal/good decisions) are almost equally important in what is known as Business Analytics (Data Analysis and Decision Making) or decision making (whether distributed or centralized). Moreover, the boundaries among strategic, tactical and operational level decision making in supply chain management (including healthcare supply chain, e.g. healthcare facility location and layouts, their mid-term logistics planning and daily operations resource allocation) are disappearing while measures of sustainability, uncertainty and environmental impacts are playing important role in an integrated decision making paradigm. This is the current trend and direction to follow –as far as traditional Operations Research is concerned– should we aim at remaining competitive whether in terms of scientific productivity or securing external funding.

In this regard, we intend to foster a much closer collaboration within LCOMS with researchers involved in both healthcare facility layout planning ('Informatique Humaine') and discrete optimisation.

2.6.2 Reinforcing and Expanding the Current Exercise

Business structures have become and are still becoming increasingly more complex systems composed of several subproblems in different disciplines and in multiple levels of decision making with multitude of stakeholders and different goals, criteria and objectives. In what concerns operational research aspects, many different analytical methods and techniques

are proposed by researchers and practitioners alike to better design and manage their systems. As the complexity has been exponentially increasing due to the increasingly more complex patterns of business and service (*e.g.* sustainability, environment, multimodality and synchronisation; various sources of uncertainty, the emerge of alliances, vertically and horizontally integrated sub-systems, cooperation and different models of economy such as shared economy etc.) the decision making has become very involved. However, on the other hand we possess loads of data (Bigdata) to be unlocked and used to analyse and extract a simplified scaffold to deliver a concise and comprehensive set of information from such complex systems.

In the last ten years, we have made an intensive investment in modeling and algorithmic aspects of problems in network design and facility location arising in very specific application areas, namely liner shipping and hub location problems. Since a couple of years ago, we have started to expand our area to make use of the experience and knowledge we accumulated in favor of other neighboring areas such as logistics of energy (e.g. LNG shipping), making use of metaheuristics to improve the performance of exact decomposition methods (mainly primal decomposition techniques such as Benders decomposition) via different techniques (warm starting, reductions, preprocessing, variable elimination etc.) and pushing towards automation of primal decomposition techniques for addressing very large scale optimization problems.

In the area of logistics in the context of energy, we will strongly continue our research activities and reinforce our closer collaboration with the current industrial partners within the framework of the ongoing PhD supervision. Other complementary/additional partners and consultancy activities will be sought in order to foster our research activities in this area and developing a sustainable strength and reputation there. As long as the logistics of energy is concerned, currently, we are also part of a team on preparing a research grant proposal on the maintenance of remote offshore energy installations.

Perhaps, access to loads of data and the open source machine learning tools has never been as easy as it is today. The area of Artificial Intelligence (AI) has been drastically reformed in the recent year and tons of open source packages become available in the favor of research in other areas as well. On the other hand, no matter how efficient, today's hardware and computational technologies imposes a sever limit on the size of problems that can be solved. Therefore, metaheuristics enriched by learning and AI techniques, thanks to the availability of extendable open source libraries, have constituted an important front of our combat in pushing the limits of computational efficiency. This has been inspired by an academic exchange with Brazil, continued by the successful thesis of Kassem Danach and a subsequence thesis of Omar Kemmar being currently under co-supervision. Our recent submissions to the Interreg programmes (Channel and 2Seas) witnesses our strong willingness and push towards securing additional resources to invest more on this area.

A very strategic and important project we are carrying out at this moment and we expect continue it in the next few years concerns automation of primal decomposition techniques to address large scale optimization problems arising in general contexts, but first on the problems we are dealing with on daily basis. Built on the top of our BENMIP project (funded by PGMO programme), we have applied and expecting some funding from various sources to further reinforce our research and development on establishing the link between the concept of *community detection* algorithms in Data Science and identification of decomposable structures in matrix of mathematical programs, to reduce the overly too emphasized and unnecessary role of experienced researchers in the success of decomposition techniques and making this success also available to a broader public.

2.6.3 Aims and Objectives

There are two main challenges (with respect to Industry 4.0 and Mobility 4.0) that our expertise will be developed around them:

Massive Data Massive data and information (over)flow introduces one additional key challenge and threat on the decision-making process: Knowledge discovery and extraction. This process includes identifying relevant sources, data modeling, polishing and cleansing, refining and correction, discovery and extraction of proper size knowledge that is going to be used in decision making process. This knowledge must be unlocked in such a way that the knowledge loss due to aggregation and abstraction is being minimized and a trade-off between the computational efficiency and the level of details is being achieved with less compromise. We intend to increase (via research funding) our capacity of data science (big-data, mining technique, computational intelligence, neural network, etc.) and promote and exploit its application in optimization and simulation techniques with particular emphasis on the healthcare logistics. We wish to concentrate on a few niches such as: 1) the link between the decision making in real-time and online massive data reception (IoT), 2) correction and knowledge discovery for use in real-time decision making and, 3) use of data science techniques (such as community detection and matrix decomposition, etc.) to automate the design of tailored decomposition methods for real-size problems in diverse set of applications in logistics (mono/multi modal logistics, healthcare, etc.) and energy sector.

Computational efficiency In the classical textbooks, the problems arising at different levels of decision making in the classical supply chains are generally of three categories: i) *Strategic* problems dealing with long term investment/impacts such as facility locations (and layout) and the portfolio of services (multimodal network infrastructures in transport and various medical services in hospitals) based on a rough information extracted from historical data and forecasts with inherent uncertainty. ii) *Tactical* problems dealing with mid-terms aspects (such as general seasonal service provisions and internal logistics and flow of material, personnel and patients in healthcare facilities or distribution services such as synchromodal operations, transshipment patterns considering measures of sustainability and environment and mid-level details over mid-term planning horizons in transport), and iii) *Operational* level activities such as scheduling, resource management, disruption management and several other activities over shorter term that generate huge datasets.

Due to the nature of transformation in supply chain (service supply) systems as per implications of Industry 4.0 and its management, the explicit frontiers between hierarchical decision making levels are disappearing. The computerization and massive data exchange, increased bandwidth and new models of business has changed the things. Locating a facility in many modern businesses is by far less a strategic or long-lasting decision but as mid-term as distribution and may even in some cases be as short-term as changing on a daily basis. Therefore, instead of three separate levels of decision in some cases, an integrated decision making becomes necessary. The challenge is the computational intractability of such decision-making system and the underlying processes. We aim at acquiring funding to further develop and reinforce our competencies in the areas such as machine learning and data science, exact optimization techniques and metaheristics to simultaneously work on modeling and hybridization of exact and metaheuristic techniques and devise methods of machine learning to derive optimal or near optimal solutions (with known quality) for integrated decision making problems. Moreover, knowledge discovery and extraction will be integrated in the classical optimization techniques to pre-process and simplify the solution processes and increase computational efficiency.

2.6.4 Activities and Related Methodology

These activities are *generally* divided into three categories.

Securing Funding We will further foster and reinforce our collaboration with highest priority at the regional and inter-regional level and also at the European level in order to increase our rate of acquiring resource/funding to increase our capacity in the aforementioned areas of research and innovation.

Increasing International Reputation We consider making the best use of acquired resources and assets to increase our international visibility by producing top-tier journals, strengthening our presence by communicating our results in the recognized international forums and to the right audiences, strengthening our presence in specialized working groups at the national and international levels.

Entrepreneurship: Consolidating our Collaboration with Industry Expanding our collaboration with the related industry, in addition to the existing collaboration with the SMEs and Start-ups in healthcare and logistics sector (port authorities and transporters) in the region. We are currently (and will continue) investing in strengthening our collaboration with the partners in digital industries and will increase our presence in the development and innovation projects.

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