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Title: Optimizing multiple truck trips in a cooperative environment through MILP and Game Theory

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List of abbreviations

In order of their appearance:

EU: European Union;

GT: Game Theory;

VRPs: Vehicle Routing Problems;

MTVRP: Multiple Trip Vehicle Routing Problems;

MIP: Mixed Integer Programming optimization Problem;

MILP: Mixed Integer Linear Programming optimization Problem;

SaaS: Software as a Service;

BPaaS: Business-Processes-as-a-Service;

3PL's: Third-party logistics;

OPEC: Organization of the Petroleum Exporting Countries;

UNCTAD: United Nations Conference on Trade and Development;

TEU: Twenty Equivalent Unit;

SC: Straddle Carriers;

RTGs: Rubber Tired Gantry Cranes;

RMGs: Rail Mounted Gantry Cranes;

AGV: automated guided vehicles;

GDP: gross domestic product;

CDS: Codice della strada;

TW: Time Window;

VRSPD-TW: Vehicle Routing Problem with Simultaneous Pickups and Deliveries and Time Windows;

RRVRP: Rollon - Rolloff Vehicle Routing Problem.

Abstract

Today, the challenge of economy regarding freight transport is to generate flows of goods extremely fast, handling information in short times, optimizing decisions, and reducing the percentage of vehicles that circulate empty over the total amount of transportation means, with benefits to roads congestion and the environment, besides economy. Logistic operators need to pose attention on suitable planning methods in order to reduce their costs, fuel consumption and emissions, as well as to gain economy of scale. To ensure the maximum efficacy, planning should be also based on cooperation between the involved subjects. Collaboration in logistics is an effective approach for business to obtain a competitive edge. In a successful collaboration, parties involved from suppliers, customers, and even competitors perform a coordinated effort to realize the potential benefit of collaboration, including reduced costs, decreased lead times, and improved asset utilization and service level. In addition to these benefit, having a broader supply chain perspective enables firms to make better-informed decisions on strategic issues.

The first aim of the present Thesis is to propose a planning approach based on mathematical programming techniques to improve the efficiency of road services of a single carrier combining multiple trips in a port environment (specifically, import, export and inland trips). In this way, in the same route, more than two transportation services can be realized with the same vehicle thus significantly reducing the number of total empty movements. Time windows constraints related to companies and terminal opening hours as well as to ship departures are considered in the problem formulation. Moreover, driving hours restrictions and trips deadlines are taken into account, together with goods compatibility for matching different trips.

The second goal of the Thesis is to define innovative planning methods and optimization schemes of logistic networks in which several carriers are present and the decisional actors operate in a cooperative scenario in which they share a portion of their demand. The proposed approaches are characterized by the adoption both of Game Theory methods and of new original methods of profits distribution.

Chapter 1

Outline of the Thesis

The arrival of mega-ships is having a profound effect on port operations and represents a challenge for ports in several ways. They have to cope with a much higher variability in delivery volumes, as one big vessel unloads much more freight. This creates demand for sufficient intermediate storage space, not only space for containers but also plug-ins for cooling and refrigerated containers, and tank storage for liquid bulk or dry bulk storage. Investments in more freight handling equipment will be necessary. Onward forwarding and distribution of cargo becomes a logistical challenge, possibly requiring additional rail and road capacity into a port. Mega-ships even have an impact on ports that can't handle them. Shippers might relocate their business to ports that can be served by mega-ships and agreement between them is necessary.

The main beneficiaries of big ships are supposed to be container shipping lines but mega vessel have filled ship overcapacity that has depressed freight rates and profit margins of shipping line. In that way collaboration between shipping companies has been useful to fill big vessels and making the service profitable both for the owner of the vessel and for the tenant. As container transport volume continues to grow, the links with the hinterland will become a critical factor the entire supply chain to effectively operate.

The access to the hinterland is a key success factor for the ports, which aim to enhance the quality of hinterland transport services [22]. To reach an adequate accessibility, as stated by [12], coordination and cooperation between a large group of actors is required. Ports and their hinterland transport systems can attract more volumes if the whole hinterland transport network is effective and efficient.

Italian infrastructures are already very close to their maximum capacity and with the arrival of big vessels the situation will get worse. This yields the necessity of increasing the effectiveness of the road transport for which one of the main issues towards rationalization and optimization is the minimization of unproductive trips. This can be beneficial, apart from an economic standpoint, also from an environmental point of view in terms of congestion and air pollution reduction.

A way to optimize road transport could be by organizing and planning road services in order to avoid empty way back also through collaboration between stakeholders realizing efficient collaboration.

So, the contribution of this study is to merge the multiple trips combination problem, based on collaborative mechanisms between partners, and the distribution of costs and profits to guarantee the best revenue for all the members of the coalition.

As will be further explained, collaboration can be realized into two directions: vertical and horizontal. During these years of studies the focus was mostly on horizontal collaboration. In the first case the collaboration is realized across different and heterogeneous levels of the supply chain and the aim is to integrate all the actors in a common agreement. In the case of horizontal collaboration we refer to collaboration among logistics operators at the same level, such as trucks operators or shippers. Partners share networks and fleets and could resort to multiple trips combination to service all the transport demand in order to optimize the general demand of transport. In particular, horizontal cooperation is proven to be effective in terms of costs reduction and improving logistics qualities but applications are still rare. The major responsible of this gap is the lack of a proper collaboration model, especially for what concerns costs/gains distribution. Therefore, any proposed mechanism to manage the collaboration's activities should yield collectively and individually desirable solutions.

At the highest level, developing a successful collaboration involves two primary tasks: identifying and exploiting synergies between individuals, and allocating the resulting benefits among the collaborators. Benefits depend on interactions between participants and identifying and exploiting synergies often involve solving complex optimization problems and thus may be quite challenging. Benefits could be divided in qualitative and quantitative. We refer to qualitative benefits as social and prestige advantages in consequence of the alliance with other partners, and are never sharable, while quantitative benefits could be sharable or not sharable. When a quantitative benefit is sharable has to be used a proper sharing method to redistribute benefits among participants and it is a crucial moment of the alliance because it must ensure that the benefits gained by each entity make the collaboration acceptable for every one and more attractive than single operability. When a quantitative benefit of the collaboration is not sharable the distribution of profits could be based on the addition of constraints such as trips deadline to ensure acceptable delivery reductions for each member.

1.1 Motivation of the Research

Road transport often lacks adequate infrastructures as well as a proper organization and planning. Therefore, a rationalization and optimization of road transportation may help improving the performance of freight transportation networks, possibly also increasing the number of delivered containers.

As stated in [55], the real keys to creating an effective road transport, and more in general an effective logistic chain, is to get the right balance between customer service and costs, this implies to manage and consider the following elements:

- *Assets.* Road freight transport fleets consist of some very high-value assets, ranging from tractors, trailers and rigid vehicles themselves to the drivers. Computer routing, scheduling packages and fleet management packages offer real opportunities to monitor very closely the costs and utilization of these assets. Both time and space (or load) utilization are important considerations.
- *Service.* Delivery transport acts as the main physical interface with the customer, so it is important that all customer service requirements are met. For transport, important requirements involve delivering within set delivery windows and meeting specific delivery times. Once again, computer routing and scheduling packages are key to achieving these goals.
- *Costs.* As well as the major assets discussed above, there are also costs associated with the operation of the vehicle, specifically the running costs such as fuel and tyres. Good scheduling can also help to keep these costs to a minimum.
- *Maintenance.* It is important to ensure that vehicles are maintained on a regular basis to reduce the occurrence of breakdowns, which can lead to both a loss of service and a higher operational cost.
- *Driver management.* This can be significantly improved by the use of appropriate tachograph analysis. As well as providing a better and more accurate picture of fleet efficiency, tachograph output can be used to monitor the detailed effectiveness of individual drivers.
- *Replacement.* A key decision for any transport manager is to be able to identify when vehicles need to be replaced and also which type of vehicle is the most effective for the particular type of operation that is being undertaken. A good fleet management system will be able to provide this information.
- *Security and tracking.* Modern technology allows for the real-time tracking of vehicles. This enables up-to-the-minute information to be provided to schedulers and to customers, so can help to improve operational effectiveness, security and service.

In this context, we found out that one of the main drawbacks of ineffective planning of road transport activities is the necessity of performing a significant number of *empty trips* [1], i.e., movements realized by vehicles without a load (which means loaded with an empty container). Empty trips are unproductive movements since they are not profitable and they also produce negative externalities on road networks, as they contribute to increase congestion phenomena and environmental pollution. The realization of empty trips may be due to an improper organization of transportation activities, but it is also often induced by the so-called “round trip” operating mode [70]. This mode refers to the case in which a truck, performing a trip from an origin point to a destination point to transfer one full container, is constrained to come back to the origin of the trip carrying back the empty container. Without a proper planning, the round trip mode frequently yields empty trips. Round trips are very common mainly due to the competition in the inland transport sector between freight forwarders and shipping companies. In fact, even if in this Thesis the case in which freight forwarders are in charge of the inland transport organization and management (that is the “merchant haulage” case is considered, as opposed to the “carrier haulage” one in which shipping lines take care of inland transportation), the decision of where to bring back the empty container is imposed by shipping companies that are the usual owners of containers. In fact, with the goal of dominating the inland transport sector, shipping companies usually oblige road carriers to bring back their empty containers to the trip origins.

The two main objectives of the present Thesis are to optimize trips route through multiple trips combination and to analyze the opportunities and challenges of collaboration in logistics services, in particular between trucks carriers.

These goals arise from the consideration that according to Eurostat studies, the trucking industry is the principal service of transports for goods in our nation (73% of the total amount), due to its intrinsic characteristics, such as easy territory penetration and flexibility. Nevertheless the statistics presented by Eurostat shows the inefficiency of the vehicle utilization, which is unsatisfactory for both own account and outsourced fleets, because about 24% of all road freight kilometers driven in the European Union are by empty vehicles. The European Environment Agency shows also that the average vehicle is loaded to 56% of its capacity in terms of weight. All of these factors make road transport the sector with the lowest profit margin mainly due to high operating costs.

This aspect with highly fragmented industry structure and intense competition has forced many small trucking companies out of business. Collaboration means sharing networks, transport demand and resources and also create optimal routes that maximize trucks utilization and avoid empty trips. Multiple trips combination could be adopted to plan more efficient routes and game theory, based on common rules, could be the solution for cost/savings distribution between partners.

So, in this Thesis exact mathematical approaches for combining multiple trips and allocate profits plus the application of game theory to share costs and benefits are presented. The innovation from previous works stands in the fact that, in the same route, more nodes can be visited, by combining

up to four trips and considering hard time constraints such as working hours restriction for drivers, that until now, according to our knowledge, have been solved only through heuristic methods.

The models are related to the context of tactical/ operative planning and truck operators own the problem of trips combination.

The expectation is that the present Thesis will give an overview of the benefits related to transport optimization that can tempt road transport operators to implement collaboration and integration.

Summary of the contribution follows:

- Firstly, we identified the problem of empty trucks movements in the containerized transport and decided to focus on a mathematical model able to combine import, export and inland trips, with a general number of two trips combined into the same route;
- Secondly, to better distribute trips we extended the study to a collaborative environment, where participants could share trips, in order to achieve higher profits and realize a more performing route planning. We modeled horizontal collaboration as cooperative games, investigate coalition formation and gain sharing issues, and then propose a set of generally applicable gain-sharing mechanisms that consider players' contribution.

1.2 Research Methodology

The multiple trips combination and horizontal collaboration have been investigated through a deep literature review both of research papers and practical cases. In particular, to make more significant the knowledge process of the sea port traffic and its consequences on road hinterland activities, specific courses on port issues and interviews with logistics operators have been carried out, in order to understand the real context of road containerized transport and to validate the models proposed in this Thesis.

The *Multiple Trip Combination Problem* presents some analogies with the class of *Vehicle Routing Problems (VRPs)* in which the optimal set of paths (routes) for a set of vehicles having to serve a set of points on a network is sought. An extensive literature is available for VRPs [9]. The problem considered in this work may be seen as a VRP but it differentiates in some aspects due to special requirements coming from real case studies. In the following subsection, an overview of the versions of VRPs which present the highest analogies with the problem under concern is provided, with a discussion of the common points and most significant differences with respect to it.

As regards the realization of collaboration between truck companies, the applications are still rare and mainly solved with simple game theory approaches or ad hoc method.

The outcome points out the need to adopt a method that simultaneously combines trips of multiple carriers and assigns costs and gains in a proper way. The multiple trips combination problem is solved applying an original Mixed Integer Linear Programming optimization problem (MILP) while the cost and profits allocations between partners is addressed applying well known Game theory methods and an original mathematical method formulated during the PhD.

To the best of our knowledge, the work here proposed is significantly different from the current existing approaches in literature. The novelty proposed stands in the approach utilized that simultaneously takes into consideration hard time constraints related to node time windows and soft time constraints related to trip deadlines, EU driving hour constraints, containerized goods feature that rarely are taken into account and the importance given to the proper allocation of saving and gains to carriers partners that join the coalition.

1.3 Structure of the thesis

The thesis is organized as follows:

- Chapter 2 provides an introduction to some basic aspect of the supply chain, focusing on containerized logistic. A description of the historical growth of container transport is followed by an assessment of its importance throughout the world. An outlook of the world economy and containerized economy is provided, with a focus on European and Italian traffics.
- In Chapter 3, the problem of the containerized truck transport inefficiencies is described. The possibility of combining trips is exploited to maximize the cost savings obtained with respect to non optimized cases. After an explicit literature review that defines the work originality, a mathematical problem is stated and solved within different optimization schemes whose comparison is addressed. Some real typical requirements as the presence of multiple ports, node time windows, trip due-dates, cargo features and EU driving rules constraints are considered. To prove the validity of the proposed approaches, various scenarios are compared by using real data provided by Italian transport operators.
- In Chapter 4 the topic of cooperation in the chain logistic chain is exploited. More in detail, the *horizontal cooperation* among truck carriers is the framework considered in the present chapter. Horizontal collaboration drivers and barriers are identified and a literature review on collaboration is proposed. The exploration of the literature is focused both on cooperative game theory and on other mechanisms of profit and cost sharing among alliances' participants.
- In Chapter 5 the problem of the profits' distribution among truck carrier operators in collaboration settings is addressed. The goal of this chapter is to properly distribute gains related to a set of carriers collaborating together after merging multiple trips applying model described in Chapter 3. The way in which the overall profit is, then, allocated to the different carriers, thus determining carrier individual profits, is analyzed by using an original mathematical model able to assign both combined and single trips to carriers. This second optimization problem is solved several times for different number of carriers participating to the coalition in order to determine the best coalition size. To analyze the efficiency of the proposed mechanism, the profit distribution is solved also applying five game theory (GT) allocation methods. An experimental campaign based on real data sets has been performed to validate the proposed approaches. Various instances considering different number of trips and different values of the coalition management cost have been analyzed.
- Chapter 6 concludes the Thesis indicating the goals achieved and the future perspectives in the horizontal collaboration framework of truck carrier operators.

Chapter 2

Introduction

The history of transportation and logistic is as long as the history of mankind. Studying the etymology of the word “Logistic” it could be deduced that it comes from the greek term “logikos” that means “that has a logical sense” and its primary root “logos” could be translated both as “word” and “order”. The first application of this term could be found within military organizations, it was the branch of military science and operations dealing with the procurement, supply, and maintenance of equipment, with the movement, evacuation, and hospitalization of personnel, with the provision of facilities and services, and with related matters. The military meaning of logistic was maintained till the second world war, where the logistic efforts reached a global scale. Logistics’ expansion towards other sectors, was formulated at the beginning of 50’s, when the relevance of the products’ transport was compared to their production. In the 80’s the concept of logistic shifted from an aggregate sequence of events to and integration of activities with higher performance levels. At 2000’s, could be settled the modern definition that applies to most industry and defines logistics as the efficient transfer of goods from the source of supply through the place of manufacture to the point of consumption in a cost-effective way whilst providing an acceptable service to the customer. The introduction of cloud computing Software-as-a-Service (SaaS) and Business-Processes-as-a-Service (BPaaS) in the 2010’s rounds out the logistics of today. Today, demanding customers, complex supply chain and ever-changing relationships with third-party logistics (3PL’s) providers are prompting supply chain management professionals to closely examine the adaptability and agility of their logistics networks, because logistics will play an ever-greater role in delivering high-performing results

It is useful, at this point, to consider logistics in the context of business and the economy as a whole. Logistics is an important activity making extensive use of the human and material resources that affect a national economy. Nowadays logistic, and the broader concept of supply chain management, is mainly intended as business function. Supply chain management gives an emphasis also on the importance of

information and its exchange between partners, and on coordination. Distribution or transportation management, as part of logistics, is a third layer in this framework where physical operations and movements of cargoes are considered (see fig.2.1). Logistics chains cover the gap between production sites and markets by choosing warehouse locations, ports of destination, inventory policies, volume and frequency of transport. In such a framework transportation takes place and the decision making concerns the routing of physical flows on networks and the choice of modality ([39]).

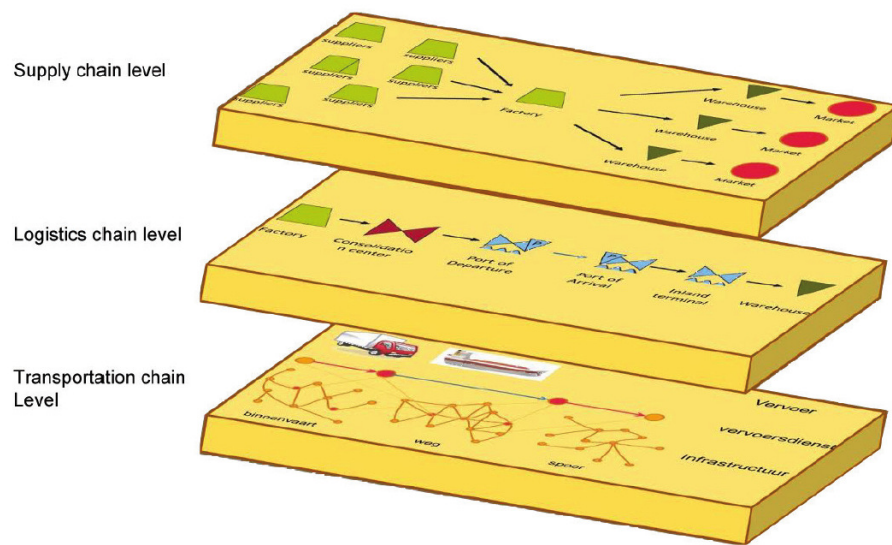


Figure 2.1: Supply Chain Hierarchy ([39])

2.1 Container Logistic

In the last decade, global trade and the movement of large quantities of goods are more and more related to supply chains based on containers (i.e. container supply chains).

To fully understand the merits and drivers of containerized cargo transport, it is beneficial to first consider the situation as it was before the era of containerization. As it is possible to see looking at Fig. 2.2 the manual handling operations of individual cargo (represented with red shapes) were significant and it meant high labour requirements that was successively translated in higher costs and less security and integrity of the cargo items. Levinson in [17], calculated the cost of transport of non containerized cargo in 1960 as the 25% of the total product's costs, and port related costs almost 50%.

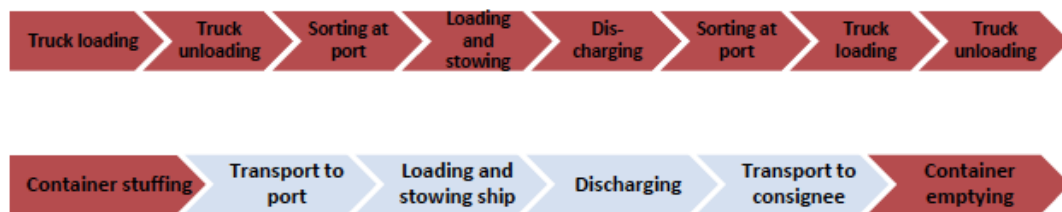


Figure 2.2: Processes of cargo handling before containerization in red shape. (from [17])

The idea of a multiple use system of goods carriage is historically attributed to Malcom McLean in 1956, to significantly reduce “time” and “costs”. It was the attempt to reduce the duration of port stays required to load/unload a vessel carrying break-bulk, that originally prompted Malcom McLean to introduce dedicated container ships, thus dramatic decreasing turnaround time and determining more efficient utilization of the expensive assets that ships are. The derived benefits propagate throughout the entire supply chain.

The rise of world containerization is the result of the interplay of macroeconomic, microeconomic and policy-oriented factors ([26]). Global trade favors the use of containers and from a logistics management perspective, containers are a challenge for both handling and transport operations. More products are moved far greater distances because of the concentration of production facilities in low costs manufacturing locations and because companies have developed concepts such as focus factories, some with a single global manufacturing point for certain products. Long-distance modes of transport have thus become much more important to the development of efficient logistics operations that have a global perspective. Containers have transformed carrier activity from a port-to-port to a door-to-door

service over different transportation modes, because transshipment can be performed easily, determining the so called “*Intermodal freight transportations*”.

In one of its most widely accepted meanings, intermodal freight transportations refers to a multimodal chain of container-transportation services. In a classical example of an intercontinental intermodal chain, loaded containers leave a shipper’s facility by truck either directly to port or to a rail yard from where a train will deliver them to port. A ship will move the containers from this initial port to a port on the other continent, from where they will be delivered to the final destination by a single or a combination of “land” transportation means: truck, rail, coastal or river navigation. Several intermodal terminals are part of this chain, such as the initial and final seaport container terminals, where are provided facilities between sea and land transport. From this description is possible to summarize with three main subsystems the intermodal container transport:

- Ocean transport;
- Sea terminals;
- Inland transport.

The container logistics, as the whole supply chain, is going through a time of rapid and unprecedented transformation. The future of logistics is paved with innovation and technology and one of the new trends are the *Collaborative relationships*, over which we decided to pose attention in this Thesis, focusing on the truck carrier operators, because in this subsystem could be found the deepest inefficiencies, as will be explained in the next sections. Nevertheless, it seems to be necessary to spend some words about each of other three subsystems that compose the intermodal transportation to better focus on the context.

2.1.1 Ocean Transport

The Ocean Transport is typically divided into three types: liner shipping, tramp shipping and industrial shipping.

Liner shipping refers to regular intervals, between named ports, and offers itself as a common carrier requiring shipment between those ports that are ready for transit by carrier's published dates. The rate of using the liner service is fixed by the carrier.

Tramp shipping is a contract-based service which offers services to selected customers who have a relatively large volume of commodities to transport. The carrier and the shipper negotiate and reach an agreement on the rate. One voyage usually carries commodities for one shipper. It satisfies the demand for spot transit and does not have a fixed itinerary for the long term.

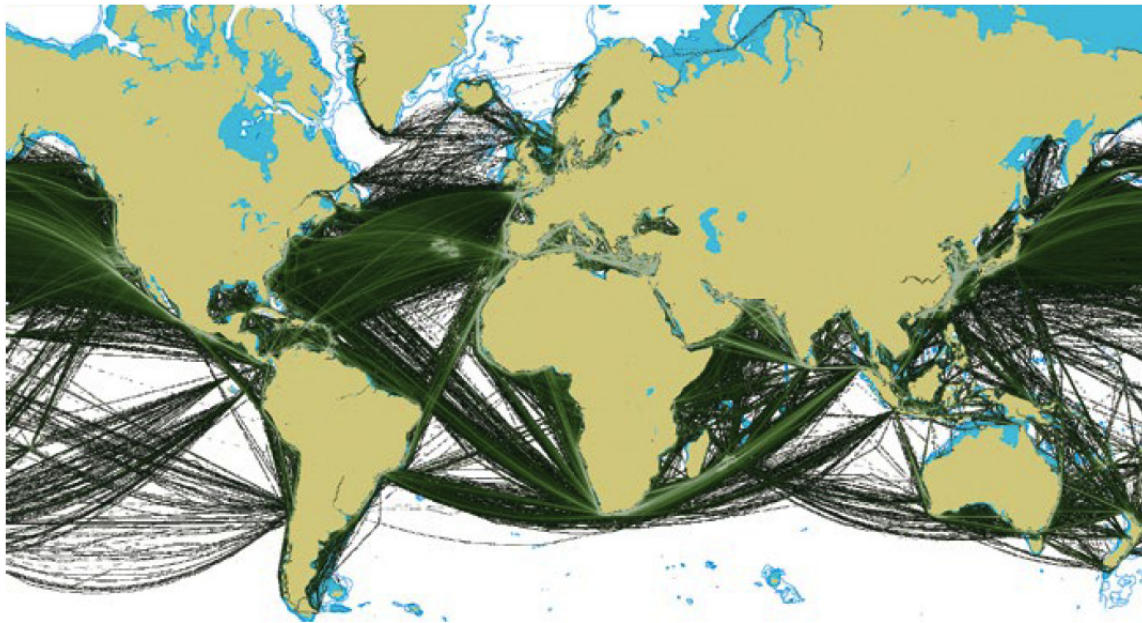
Industrial shipping, also called special shipping, is characterized by its running on regular routes using specialized ships for certain goods. Big industrial organizations with large volumes of input materials or output products, for example, the Organization of the Petroleum Exporting Countries (OPEC), represent the major demand for industrial shipping. Industrial organizations usually cooperate and have their own fleets or rent fleets for long periods of time in order to transport goods.

Containerized transport is mostly executed by linear shippings. Container ships have a fixed schedule and call at several ports during a journey.

Figure 2.3 represents the density map of container ships in 2016. Key nodes are Malacca, Panama, the Strait of Gibraltar and Suez, and traffic is denser in general in the northern hemisphere than in the southern hemisphere, with exceptions, for example around Santos (Brazil), South Africa and Mauritius. Some locations are better connected than others, and it is worthwhile to understand the reasons for these differences and options for improvement.

UNCTAD evaluates the global linear shipping network adopting a connectivity index composed of five elements: the number of ships deployed to and from each country's seaports, their combined container-carrying capacity, the number of companies that provide regular services, the number of services and the size of the largest ship. In Fig.2.4 the index trends for the regions are illustrated: a) West Coast, South America; b) East Coast, South America; c) African hubs; d) Eastern Africa; e) Western Asia; f) Southern Asia; g) South East Asia; h) Eastern Asia.

Shipping industry is significantly influenced by containerization. Container ships are the work-horses of the globalized economy: although they represent only one eighth of the total world fleet they are essential for the transport of consumer goods around the world. Container ships have grown bigger at a rapid pace over the last decades, faster than any other ship type. In one decade, the average capacity of a container ship has doubled. In 2016, 127 new containers ships were delivered (figures 2.5 and 2.6), 70% less than the peak of 2008 when the delivered ships where 436. The combined



Source: Prepared for UNCTAD by Marine Traffic.
 Note: Data depict container ship movements in 2016.

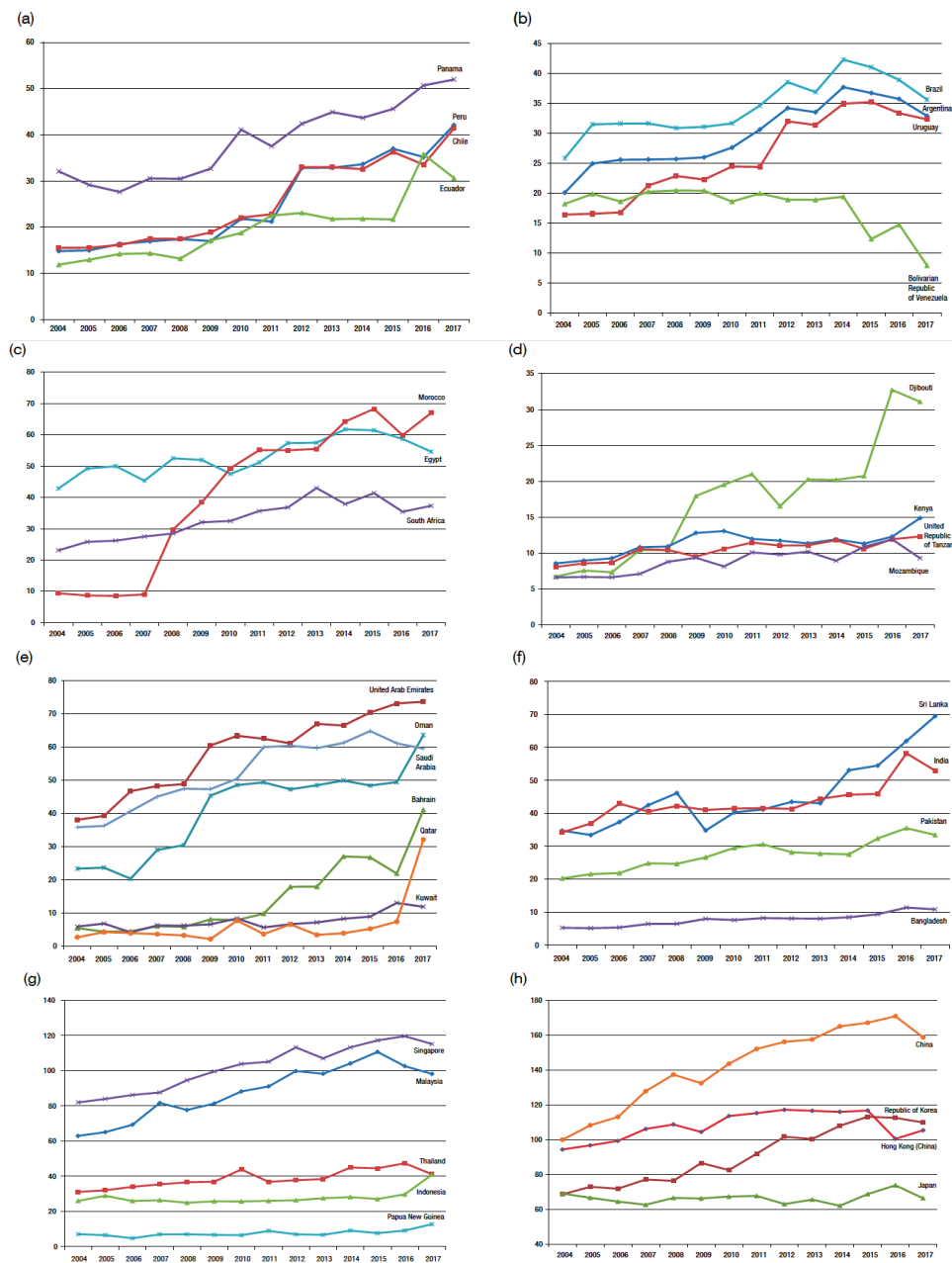
Figure 2.3: World Container Trade in 2017

TEU capacity amounted to less than 904 thousand TEU, a reduction by almost half, compared with deliveries in 2015.

The trend towards gearless ships continued: Only 4.1% of delivered TEU capacity was on ships capable of calling in ports that did not have their own ship-to-shore container handling equipment.

Economy of scales at sea is the greatest advantage of mega container vessels. The new building price for bigger container ship was higher than smaller one but in term of investment per TEU, the bigger ship is less cost than the smaller ship. Moreover, the vessel with two times bigger, not going to consume two time fuel and fuel consumption per TEU always favors for big container ship. So, economy of scale are achieved both in building and operating costs [74].

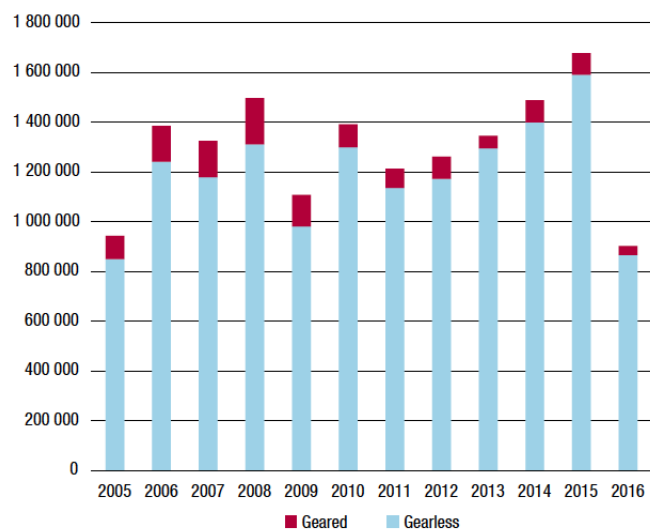
Mega vessels brought the drawback of the depression of freight rates and profit margins of shipping lines due to the overcapacity. This has determined the creation of form of mergers and acquisitions and alliances. Although there have been mergers in recent years the major consolidation tendency has been the emergence of alliances, in that way collaboration between shipping companies has been useful to fill big vessels and making the service profitable both for the owner of the vessel and for the tenant. In 2017, only three big alliances represent nearly 80% of global container trade and roughly 90% of container capacity on major trade routes. The main trade lane that



Source: UNCTAD secretariat calculations. For the liner shipping connectivity index of each country, see <http://stats.unctad.org/LSC> for the calculation, see endnote 2.

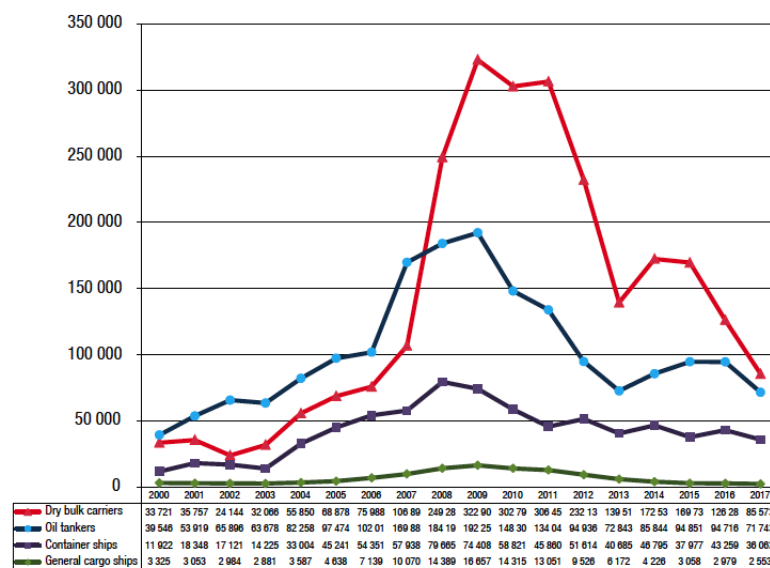
Figure 2.4: Linear Shipping Connectivity 2004-2017

is highly affected by this change and the main reason for the new alliances is the North America-Asia a.k.a. “East-West” trade lane between the Far East and North America which will represent 96% of East-West trade. These three big Ocean Carrier



Source: UNCTAD secretariat calculations, based on data from Clarksons Research.
 Note: Propelled seagoing vessels of 100 gross tons and above.

Figure 2.5: Container Ship Deliveries, 2005-2016



Source: UNCTAD secretariat calculations, based on data from Clarksons Research.
 Notes: Propelled seagoing merchant vessels of 100 gross tons and above; beginning-of-year figures.

Figure 2.6: World Tonnage on order 2000-2017

Alliances are (Fig.2.7):

- Alliance: CMA CGM, COSCO, OOCL, APL and Evergreen (APL is now owned by CMA CGM);
- The Alliance: ONE, itself composed by NYK Group, MOL and K Line; Hapag Lloyd, UASC and Yang Ming (UASC has merged with Hapag Lloyd);
- 2M Alliance: Maersk Line and MSC, with HMM and Hamburg Sud (Hamburg Sud is now owned by Maersk Line). HMM is not officially in the alliance, but they have slot purchases and exchanges with MSC as well as Maersk.

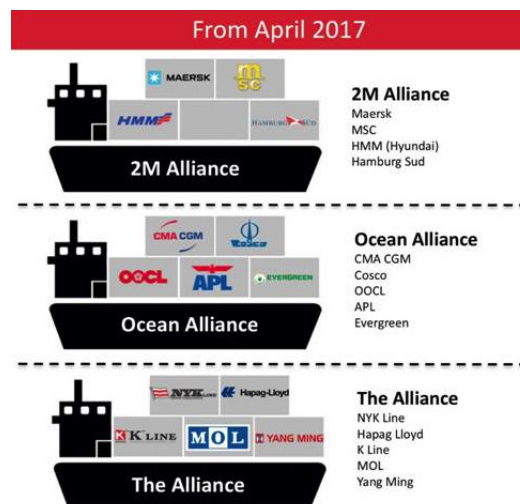


Figure 2.7: Freight transport modal share by country (percentage of tonne kilo metres)

The three alliances, which include the top 10 container shipping lines plus K-Line, the fourteenth largest container shipping line in the world, collectively control 77 % of global container ship capacity, leaving a 23 % market share for the world's other container shipping lines. The three alliances also control as much as 92 % of all East-West trade. The Ocean Alliance will be the dominant player on the East-West routes, with about 34 % of total capacity deployed on these trade routes, followed by the 2M Alliance, with a share of 33%, and The Alliance, 26 % ([95]).

In Fig.2.8 the container ship fleet ownership in TEU are showed. Germany continues to be the largest owner, with a market share of 21.46 %, followed by China and Greece. The largest container ships of 17,000 TEU and above are owned by carriers from China, Hong Kong (China), Denmark, France and Kuwait. German and Greek shipowners, most of which are not liner shipping companies, do not own any container ships of this size. They are primarily charter-owners, namely companies that charter their ships out to liner companies that provide a particular shipping service.

Maersk (Denmark) continues to be the largest liner shipping company in terms of operated container ship capacity (3.2 million TEU), followed by MSC (Switzerland)

	20-foot equivalent units	Market share (percentage)	Number of ships	Size of largest ship (20-foot equivalent units)	Average size per ship (20-foot equivalent units)
Germany	4 795 085	21.46	2 106	14 036	2 277
China	2 098 655	9.39	871	19 224	2 409
Greece	1 815 265	8.13	563	14 354	3 224
Denmark	1 548 865	6.93	300	18 270	5 163
Hong Kong (China)	1 383 720	6.19	288	17 859	4 805
Singapore	1 368 888	6.13	448	15 908	3 056
Japan	1 240 871	5.55	410	14 026	3 027
Switzerland	1 225 932	5.49	236	14 000	5 195
Taiwan Province of China	977 453	4.38	280	8 626	3 491
United Kingdom	873 348	3.91	337	15 908	2 592
Republic of Korea	667 571	2.99	254	13 100	2 628
France	592 738	2.65	95	17 722	6 239
Kuwait	457 918	2.05	42	18 800	10 903
United States	351 895	1.58	206	9 443	1 708
Netherlands	302 313	1.35	646	3 508	468
Turkey	262 955	1.18	512	9 010	514
Norway	229 220	1.03	365	13 102	628
Indonesia	183 479	0.82	410	2 702	448
Israel	178 623	0.80	42	10 062	4 253
Cyprus	174 513	0.78	123	6 969	1 419
Top 20 owners subtotal	20 729 307	92.79	8 534		2 429
Rest of world	1 610 491	7.21	2 616		
World total	22 339 798	100.00	11 150	19 224	2 004

Source: UNCTAD secretariat calculations, based on data from Clarksons Research. For a complete listing of nationally owned fleets in dwt, see <http://stats.unctad.org/fleetownership> (accessed 9 September 2017).

Notes: Propelled seagoing vessels of 1,000 gross tons and above; beginning-of-year figures. The table also includes ships other than specialized container ships, with some container-carrying capacity.

Figure 2.8: Ownership of container-carrying world fleet, 2017 (Twenty-foot equivalent units)

and CMA CGM (France). Most liner shipping companies own about half the ships they deploy on their services, while the other half is chartered in. Nevertheless should be noted that more than 70% of the commercial fleet is registered under a flag that is different from the country of ownership, more than 76.2 % of the world fleet tonnage is registered in the developing countries, such as Panama, Liberia and the Marshall Islands. However, some of the nationally flagged fleets are also nationally owned, often because of cargo reservation regimes that limit the options for shipowners to flag out. Many of the ships flying the flags of China, India, Indonesia and the United States are deployed on domestic transport (cabotage) services, which are reserved for nationally registered ships.

2.1.2 Sea containerized terminals

Ocean containerized transports start and end at container port terminals.

The main function of a container port terminal is to provide transfer facilities for containers between sea vessels and land transportation modes, trucks and rail in particular. It is a highly complex system that involves numerous pieces of equipment, operations, and container handling steps. A port terminal can be divided in three areas:

1. The *sea side* area encompasses the quays where ships berth and the quay cranes that provide the loading and unloading of containers into and from ships.
2. The *yard side* area, where containers are transferred to land transport modes or are arranged to be loaded on to other ships. Two types of activities are performed in this area: the stacking of containers and horizontal transport. Stacking equipment for containers includes Straddle Carriers (SC), Rubber Tired Gantry Cranes (RTGs), Rail Mounted Gantry Cranes (RMGs), Reach stackers, and Stackers for Empty Containers. The horizontal transport between the Quay side and yard side is performed by terminal trucks, trailers, straddle carriers or automated guided vehicles (AGV) and reach stackers.
3. The *land side* area provide services for receiving/delivery operations for outside trucks and trains

Figure 2.9 illustrates the three areas of a container port terminal.

Inside the Terminal three main cycles can be distinguished:

1. Import cycle: this cycle starts from the sea side with the arrival of the ships and ends in the land side. The arrival time is known in advance and should respect the dedicated berthing window, determined by commercial agreement with the shipping lines. Successively a certain number of quay cranes are assigned to follow the stowage sequence. Stowage sequencing determines the sequence of unloading and loading containers, as well as the precise position each container being loaded into the ship is to be placed in. During the unloading operation, a quay crane transfers a container from a ship to a transporter (for instance a straddle carrier or a trailer) that brings the container to yard area, where a yard crane picks it up and stacks it into a given position in the yard.
2. Export cycle: this cycle starts from the land side and ends in the sea side. When a container arrives at the gate of the terminal is firstly inspected to check for damages and if documents are in order, then information regarding where the container is to be stored is provided to the truck driver. Once reached the correct yard area, a yard crane lifts the container from the truck and properly stacks as planned. Similarly, also for a container from rail, the first phase regards the physical and documental check, then it is picked up by a gantry crane to a transporter that delivers it to the yard.

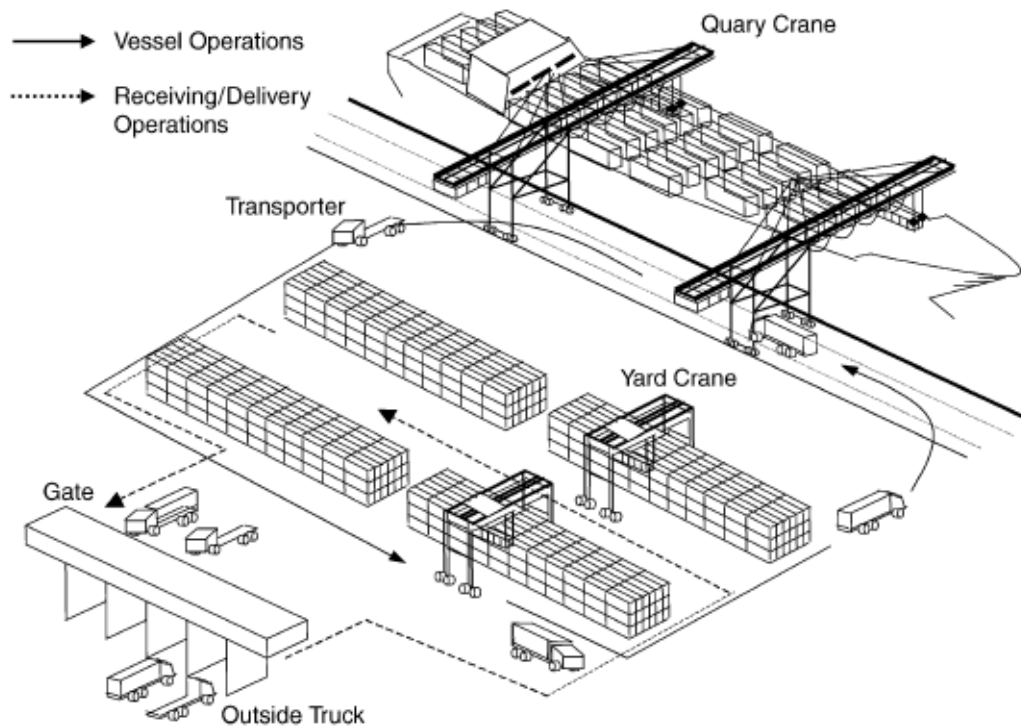


Figure 2.9: Port Container Terminal Layout ([10])

3. Transshipment cycle: this cycle starts and ends in the sea side. Containers are unloaded from a ship, temporary stored in the yard, and then reloaded into a second vessel, without leaving the terminal yard.

Looking at the terminal's activities from the Operational research perspective, several decision problems can be identified, as these involve policies guiding the storage block with regard to container features such as weight, sizes, country of destination, import and export container dispatch, type of goods in the container, etc. Yard storage space is pre-assigned to containers of each ship arriving in the near future to maximize the productivity of the loading and unloading operations. They are known as space allocation problems. Inbound containers are usually unloaded fast not to delay the ship departure, but are retrieved over a long period of time compared to the ship unloading time, in a somewhat random sequence due to uncertainties related to importing formalities and the operations of land transportation modes. The minimization of the number of container rehandlings is, thus, the most important issue in this case. Pre-planning storage spaces for arriving containers will result in less re-handlings and a more efficient ship loading operation ([27]).

Other important activities connected to the port stay of the vessels are the berth

scheduling and quay crane assignment problems. The first one is the process of determining the time and position at which each arriving vessel will berth. Quay-crane allocation is the process of determining the vessel that each quay crane will serve and the time during which the quay crane will serve the assigned vessel.

Optimally solving the stowage allocation problems are determined the sequence of unloading inbound containers and loading outbound containers. The slot into which each of the outbound containers will be stacked must be determined simultaneously. When an indirect transfer system is used, yard cranes move containers between yard stacks and yard trucks. The loading sequence of individual containers thus impacts significantly the total distance traveled by yard cranes and hence the total handling cost in the yard. This is not the case when a direct transfer system is used since the yard handling cost is determined by the cost of yard truck movements only, which is independent of the container loading sequence. In the stowage (load/unload) sequencing problem, it is usually assumed that the stowage plan is already constructed and provided by the vessel carrier.

New challenges for terminal operations are represented by arrival of mega ships. Mega-ships increase pressure on terminals with lower frequency services and greater throughput peaks for ports and terminals to deal with ([68]). Carrier alliances have caused an increase in container re-handles due to the extraordinary randomness of container discharges ([67]). Additionally, mega-ships require significant port and terminal infrastructure modification that can be financially challenging to meet. Below are described the main consequences:

Firstly, the draft limitation: most hub ports do not have enough draft which mega container can berth easily without any draft limitation. One more, larger container ships normally call at fewer ports. The physical features of such ships and handling requirements add pressure to berth and crane operations.

Secondly, to quickly service the larger-sized ships, terminal operators use cranes over longer working hours and more shifts, so the lack of crane ability can be another reason escalating the lack of port facilities. Additionally, larger port calls may require ships to spend more time at berth, which in turn reduces crane availability. More time is also required to lash and unlash container berths ([88]).

Thirdly, the limited berth size is other demerit for mega ship, are also less flexible in port area, they have limited choice to come along side berth with their side, so it may result in longer time stay in port and also will negatively affect economies of scale.

Larger ship calls are often associated with lower service frequency and periods of peak volumes at port terminals. Peak volumes handled by larger vessels lead to over utilization of port capacity on some days and underutilization on others ([80]). As a result, a reduction in berth utilization measured in TEU per metre of berth has been observed.

Fourthly, greater cargo volumes per calls, create surges and pressures on yard

operations, given the ensuing peaks.

As more equipment is required to move containers to and from stacking areas, additional equipment and labour are necessary. Pressure is also imposed on the restacking of containers through increased requirements for gantry cranes of yards and stacking density. For specialized cargo such as refrigerated goods, larger port call volumes exert pressure on the usage of reefer slots.

Another challenge, less developed hinterland facilities are one of drawbacks for mega container ships in port. Hinterland is the area of land behind or around coast, it has various types of facilities related to operate container including container yard, warehouse, and road for land transportation. Therefore, hinterland influences to the container operation directly.

Sharp increases in cargo volume also create greater demands on gate access, with more trucks arriving and leaving with larger numbers of containers. This creates more local congestion as more trucks are waiting to enter the port. Overall, large container ships provide economies of scale at sea, but these economies do not necessarily extend to ports. One study finds that a 1 % growth in ship size and its auxiliary industry operations increases time in port by nearly 2.9 % and creates diseconomies of scale at ports, indicating that economies of scale that are gained at sea are lost at ports ([89]). The challenge with larger ships is how to avoid lost time at berths, as ships take up more space and remain in port longer ([81]).

Finally, especially for smaller ports in developing regions, is how to decide on the design of terminals, type of cargo-handling equipment to invest in, extent of automation and digitalization of equipment, type of technology to adopt, and port and staffing-level management ([92]). While there will be winners and losers in this new operating landscape, the extent of the associated gains and losses are yet to be fully understood.

As stated during the International Transportation Forum of 2016 [75], *cooperation* between terminal operators is not unusual. Since the proliferation of the landlord model of port governance in which the port authority keeps certain regulatory functions but delegates port operations to private operators various countries have adopted legislation that only allows global port operators in joint ventures with local operators, in many case with a majority stake of the local operator. What is fairly new is the cooperation between the largest global terminal operators. For some global terminal operators these joint ventures start to make up a substantial part of their terminal portfolio. For the moment, most of these joint ventures are concentrated in certain geographical areas, in particular China, West Africa and North Europe, but the number of joint ventures of global terminal operators is expected to grow . Some terminal operators have also stakes in other operators, most notably PSA that has a 20% stake in HPH. Although certain pairs of terminal operators are more common than others it might be too early to conclude that alliances of global terminal operators

are emerging.

This might at some point become a concern for competition authorities and legislators. The effects of terminal cooperation and consolidation will differ from place to place, and general guidelines are not all together straight forward. A reasonable amount of competition between port terminals is clearly in the public interest, also because competition between ports is in many places limited because of their natural gateway functions that cannot easily be replaced by other ports. At the same time, the reality of mega ships would sometimes suggest the consolidation of certain terminals, e.g. in order to create the required berth lengths or yard space. Sometimes, port laws are restrictive in the terminal extensions they allow; e.g. in Mexico the Port Law stipulates that port terminals can extend their area up to 20%; if they would like to exceed such limit, they would need to bid for a new terminal [75]. The alternative is relocation of part of the port, which could be disadvantageous to incumbent port terminal operators, considering that they are frequently excluded from bidding for reasons of competition. In some countries with terminal fragmentation, port laws would need to be evaluated in order to assess if the legislation is “mega-ship-ready”, that is: providing enough flexibility to terminal operators and port authorities to renegotiate concessions within the light of changing realities filled by mega-ships.

2.1.3 Inland Transport

As container transport volume continues to grow, the links with the hinterland will become a critical factor for the seaports competitive advantage, therefore progress only in maritime part of the transport chain and in seaport terminals, without improvements in seaport inland access, is not sufficient for the entire transportation chain to effectively operate.

For continental movements, road freight transport continues to be the dominant mode of transport. A look at recent European statistics confirms this. The upward trend in the use of road transport has continued for many years, and it seems unlikely that the importance of road freight transport will diminish in the near future. Rail freight has remained relatively static for some time, but has increased slightly in recent years.

The diffusion of road freight transport as first means of goods' transport is evident in Fig. 2.10, where the modal split is compared for freight movements within individual countries. Rail freight transport is prevalent in USA, Switzerland, Hungary and Australia, where there are significant environmental issues and restrictions.

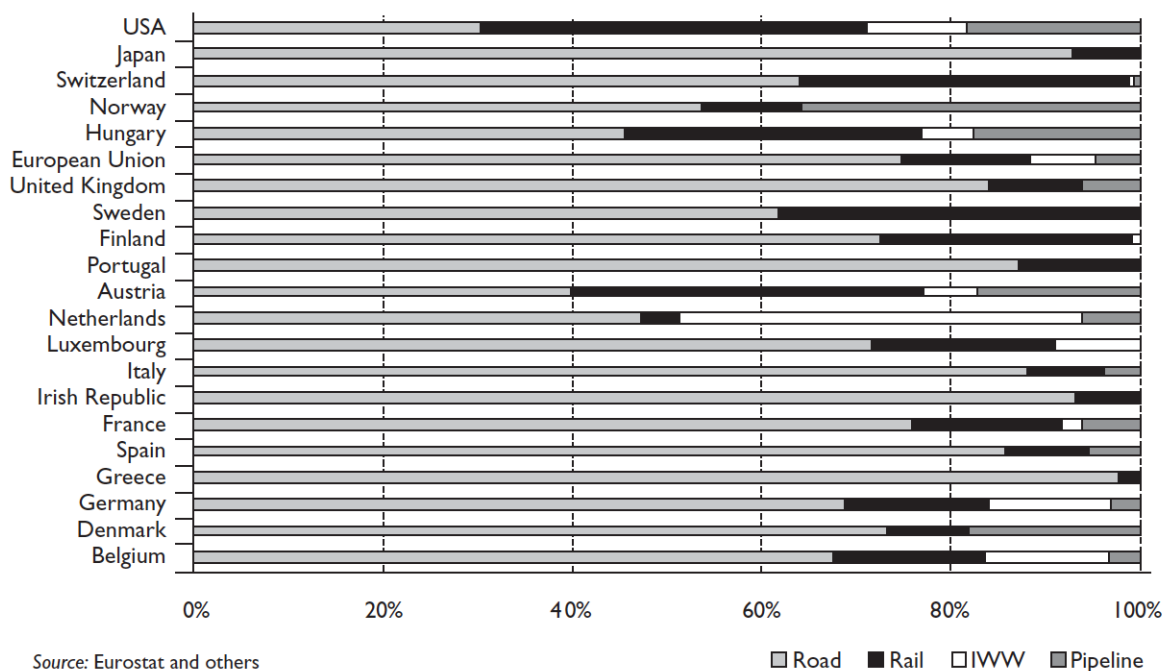


Figure 2.10: Freight transport modal share by country (percentage of ton-kilometres)

The access to the hinterland is a key success factor for the ports, which aim to enhance the quality of hinterland transport services [22]. To reach an adequate accessibility, as stated by [12], coordination and cooperation between a large group of actors is

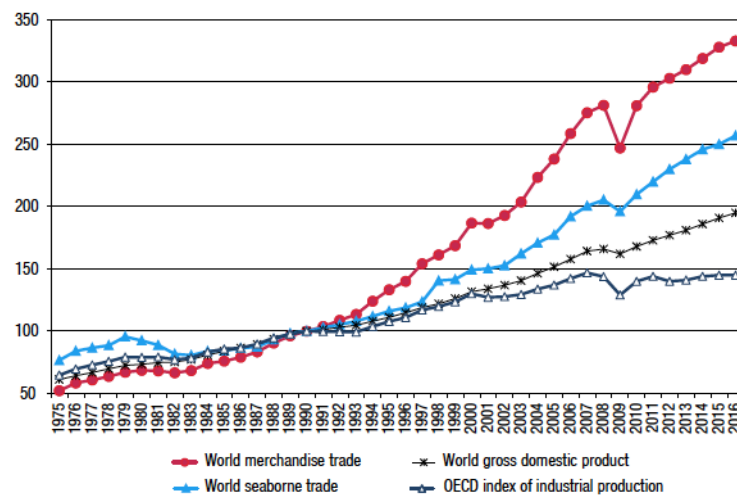
required. Ports and their hinterland transport systems can attract more volumes if the whole hinterland transport network is effective and efficient.

Italian infrastructures are already very close to their maximum capacity and with the arrival of big vessels the situation will get worse. This yields the necessity of increasing the effectiveness of the road transport for which one of the main issues towards rationalization and optimization is the minimization of unproductive trips. This can be beneficial, apart from an economic standpoint, also from an environmental point of view in terms of congestion and air pollution reduction.

A way to optimize road transport could be by organizing and planning road services in order to avoid empty way back also through collaboration between stakeholders realizing efficient collaboration.

2.2 World Economy: economical value of containerized transport

World containerized trade continues to be largely determined by developments in the world economy and trade, as well the generic merchandise trade. According to Organization for Economic Cooperation and Development (OECD) studies published in 2017, although the relationship between economic output and merchandise trade seems to be shifting, with an observed decline in the growth ratio of trade to gross domestic product (GDP) over recent years, demand for maritime transport services remains heavily dependent on the performance of the world economy. While industrial activity, economic output, merchandise trade and seaborne trade shipments may be growing at different speeds, these variables remain, nevertheless, positively correlated, as shown in Fig.2.11.



Sources: UNCTAD secretariat calculations, based on data from OECD, 2017; United Nations, 2017; UNCTAD *Review of Maritime Transport*, various issues; World Trade Organization, 2012.
Note: Index calculations are based on GDP and merchandise trade in dollars, and seaborne trade in metric tons.

Figure 2.11: Gross domestic product, merchandise trade and seaborne shipments, 1975-2016

Looking closely to the last years (Fig. 2.12), in 2016 the GDP growth of both Developed and Developing economies, decelerated due to weak global investment environment, limited growth in world merchandise trade, increased trade policy uncertainty and the continued negative impact of low commodity price levels both on investment and the export earnings of commodity-exporting countries. In 2017, the world economy and merchandise trade is expected to improve somewhat. However, uncertainty and other factors, both positive and negative, continue to shape this outlook. In this context, UNCTAD estimates that seaborne trade will increase by

2.8 %, with total volumes reaching 10.6 billion tons. Its projections for the medium-term point to continued expansion, with volumes growing at an estimated compound annual growth rate of 3.2 % between 2017 and 2022. Volumes are set to expand across all segments, with containerized trade and major dry bulk commodities trade recording the fastest growth.

The comparison between GDP and containerized transport could be also focused to Europe Union at 28 countries. Figure 2.13 represent the trends of this duality from 2006 to 2016.

Region or economic grouping	2001–2008	2015	2016	2017
World	3.2	2.6	2.2	2.6
Developed economies	2.2	2.2	1.7	1.9
<i>of which:</i>				
United States	2.5	2.6	1.6	2.1
European Union 28	2.2	2.3	1.9	1.9
Japan	1.2	1.2	1.0	1.2
Developing economies	6.2	3.8	3.6	4.2
<i>of which:</i>				
Africa	5.7	3.0	1.5	2.7
Asia	7.3	5.2	5.1	5.2
China	10.9	6.9	6.7	6.7
India	7.6	7.2	7.0	6.7
Western Asia	5.8	3.7	2.2	2.7
Latin American and the Caribbean	3.9	-0.3	-0.8	1.2
Brazil	3.7	-3.8	-3.6	0.1
Least developed countries	7.2	3.6	3.7	4.4
Transition economies	7.1	-2.2	0.4	1.8
Russian Federation	6.8	-2.8	-0.2	1.5

Source: UNCTAD, 2017a.

Note: Data for 2017 are projected figures.

Figure 2.12: Annual percentage change of World economic growth, 2015-2017

The total TEU handled in European ports (EU28) suffered from the economic and financial crisis which started in late 2008. The year 2009 brought a TEU drop of 14% in the EU port system with some ports recording even much higher losses (e.g. Hamburg saw a TEU volume drop of 28%), while a slight decrease of the GDP. Since 2012, growth figures in container handling show a modest growth between 2.5% and 5% per annum followed by a significant increase of the GDP.

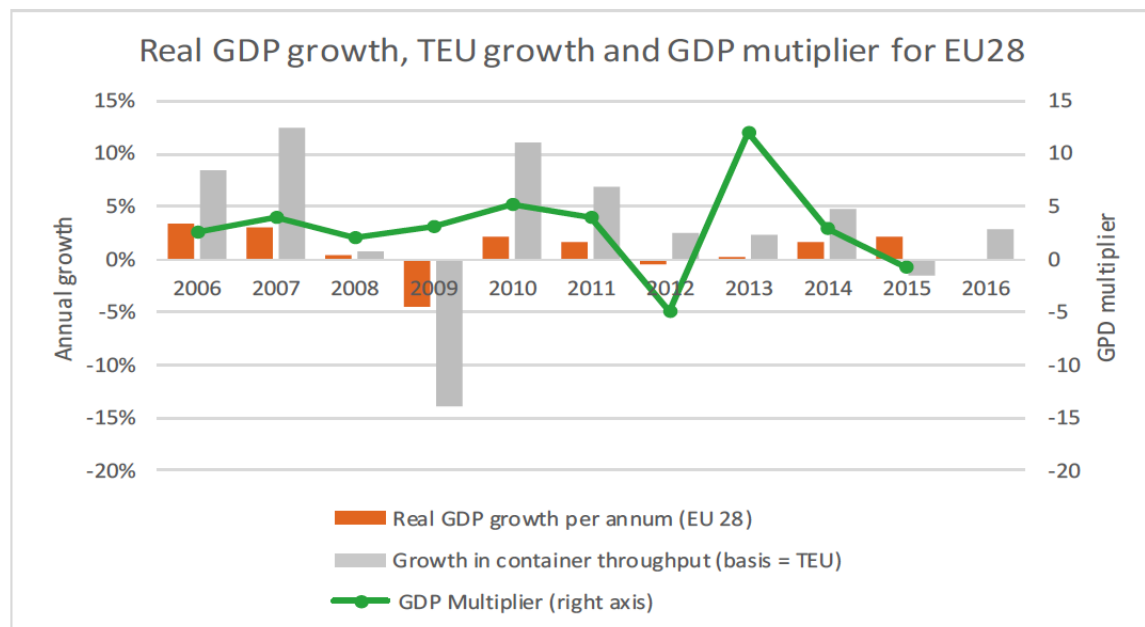
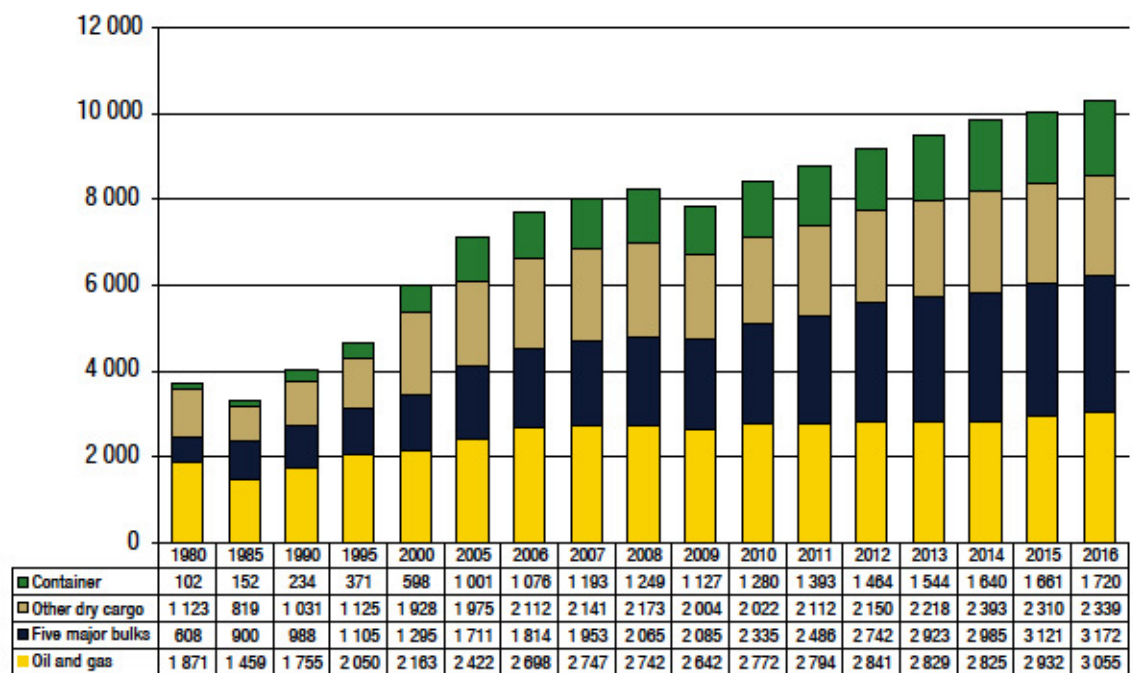


Figure 2.13: Evolution of the GDP compared to the container throughput in EU 28

2.2.1 World merchandise trend: actual and future value

As previously anticipated, the container throughput is one of the main driver of the global economy and in this section is provided a detailed analysis of the world performance. In 2016 Total volumes reached 10.3 billion tons, reflecting the addition of over 260 million tons of cargo, about half of which was attributed to tanker trade, as showed in Fig. 2.14.

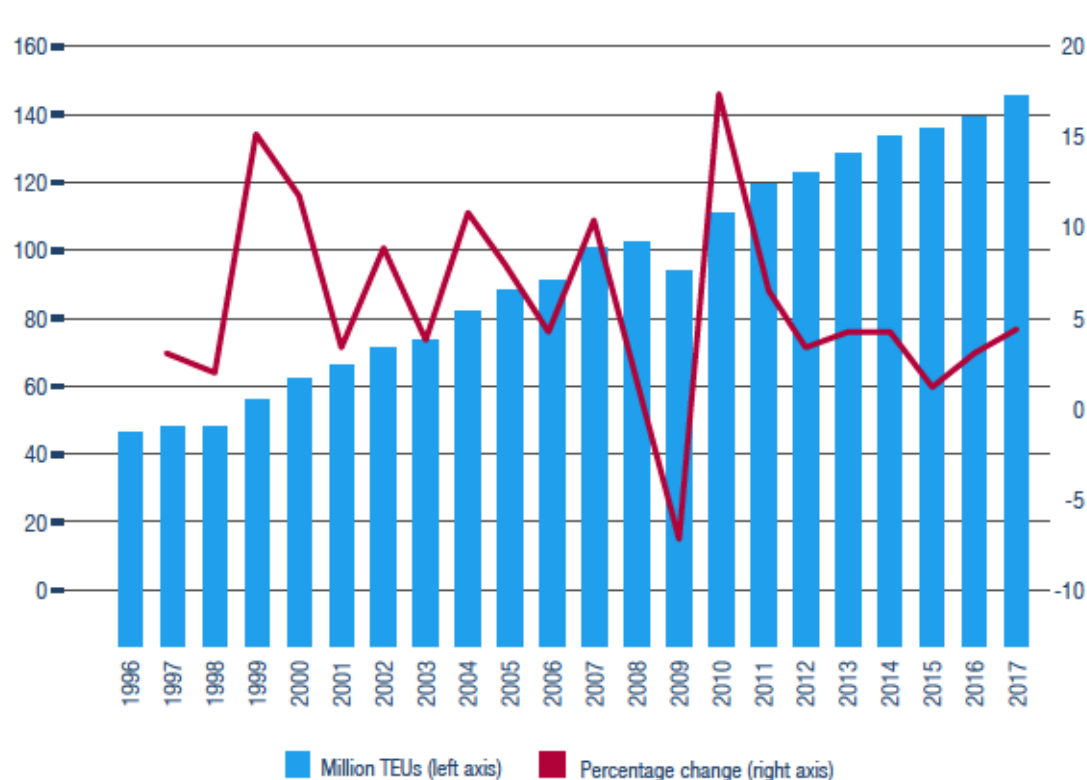


Sources: *Review of Maritime Transport*, various issues. For 2006–2016, the breakdown by cargo type is based on data from Clarksons Research, *Shipping Review and Outlook* and *Seaborne Trade Monitor*, various issues.

Figure 2.14: International seaborne trade, selected years (Millions of tons loaded), 1980-2016

Looking at the containerized trade, in figures 2.15 and 2.16 it can be seen an expansion at a faster rate of 3.1 % in 2016, with volumes attaining an estimated 140 million 20-foot equivalent units (TEU) ([95]). This recovery could be justified with the accelerated growth in intra Asian cargo flows and positive trends in the trans Pacific, with boules exceeding 25 million TEU. Volumes on the trans Atlantic trade route increased by 2.9 %, reaching 7 million TEU in 2016.

As regards the future trends (see Fig. 2.17), UNCTAD forecasts an increase in world seaborne trade volumes between 2017-2022 across all segments, with containerized



Source: UNCTAD secretariat calculations, based on data from MDS Transmodal, 2017.

Note: Data for 2017 are projected figures.

Figure 2.15: Global containerized trade, 1996-2017 (Million 20-foot equivalent units and annual percentage change)

trade and major dry bulk commodities recording the fastest growth. Containerized trade is projected to grow by 4.5 %, owing mainly to growing intra-Asian trade volumes and improved flows on the East-West main lanes. The projections see an annual compound growth rate of 3.2 %, in line with some existing projections, including by Clarksons Research and is consistent with the historical average annual growth rate of 3 % estimated by UNCTAD in 1970-2016. This volumes increase is likely to be supported by infrastructure development projects such as the One Belt, One Road initiative (China), the International North-South Transport Corridor (India, the Russian Federation and Central Asia) and the Quality for Infrastructure Partnership (Japan).

Year	Trans-Pacific Eastbound	Westbound	Asia-Europe Eastbound	Westbound	Trans-Atlantic Eastbound	Westbound
	Eastern Asia– North America	North America– Eastern Asia	Northern Europe and Mediterranean to Eastern Asia	Eastern Asia to Northern Europe and Mediterranean	North America to Northern Europe and Mediterranean	Northern Europe and Mediterranean to North America
2014	15.8	7.4	6.8	15.2	2.8	3.9
2015	16.8	7.2	6.8	14.9	2.7	4.1
2016	17.7	7.7	7.1	15.3	2.7	4.3
2017	17.9	8.2	7.6	15.5	2.9	4.5
Annual percentage change						
2014–2015	6.6	-2.9	0.0	-2.4	-2.4	5.6
2015–2016	5.2	7.3	4.0	2.8	0.5	3.3
2016–2017	1.0	6.4	7.3	1.8	6.7	4.5

Source: UNCTAD secretariat calculations, based on data from MDS Transmodal, 2017.
Note: Data for 2017 are projected figures.

Figure 2.16: Containerized trade on major East-West trade routes, 2014-2017 (Million 20-foot equivalent units and annual percentage change)

	Growth rates	Years	Seaborne trade flows	Source
Lloyd's List Intelligence	3.1	2017–2026	Seaborne trade volume	<i>Lloyd's List Intelligence research, 2017</i>
	4.6	2017–2026	Containerized trade volume	
	3.6	2017–2026	Dry bulk	
	2.5	2017–2026	Liquid bulk	
Clarksons Research Services	3.1	2017	Seaborne trade volume	<i>Seaborne Trade Monitor, June 2017</i>
	4.8	2017	Containerized trade volume	<i>Container Intelligence Monthly, June 2017</i>
	5.1	2018	Containerized trade volume	<i>Container Intelligence Monthly, June 2017</i>
	3.4	2017	Dry bulk	<i>Dry Bulk Trade Outlook, June 2017</i>
	2.1	2017	Liquid bulk	<i>Seaborne Trade Monitor, June 2017</i>
Drewry Maritime Research	1.9	2017	Containerized trade volume	<i>Container Forecaster, Quarter 1, 2017</i>
Maritime Strategies International	3.7	2017	Containerized trade volume	<i>Dynamar B.V. Dynaliners Monthly, May 2017</i>
	4.5	2018	Containerized trade volume	
	4.5	2019	Containerized trade volume	
McKinsey	3.0	2017	Containerized trade volume	<i>Dynamar B.V. Dynaliners Monthly, May 2017</i>
IHS Markit	By a factor of 2.7	2016–2030	Seaborne trade value	<i>IHS Markit research, 2016</i>
UNCTAD	2.8	2017	Seaborne trade volume	<i>Review of Maritime Transport 2017</i>
	4.5	2017	Containerized trade volume	
	5.4	2017	Five major bulks	
	0.9	2017	Crude oil	
	2.0	2017	Refined petroleum products and gas	
UNCTAD	3.2	2017–2022	Seaborne trade volume	<i>Review of Maritime Transport 2017</i>
	5.0	2017–2022	Containerized trade volume	
	5.6	2017–2022	Five major bulks	
	1.2	2017–2022	Crude oil	
	1.7	2017–2022	Refined petroleum products and gas	

Sources: UNCTAD secretariat calculations, based on own calculations and forecasts published by the indicated institutions and data providers (column 5 of table).

Note: Figures by Lloyd's List Intelligence and UNCTAD are compound annual growth rates. Figures for the other sources are annual percentage changes.

Figure 2.17: Seaborne trade developments, 2017-2030

2.2.2 World Port Container traffics: actual values and future trends

Economical trends of ports are strictly related to the deployment of ever larger ships, cascading of vessels from main trade lanes to secondary routes, growing concentration in liner shipping, heightened consolidation activity, a reshuffling of liner shipping alliances and growing cyber security threats.

World Container Terminals's throughout is continuously increasing, 76 % of total volumes handled in 2016 were accounted for by full containers, and 24 %, by empty containers ([87]). Trans-shipment incidence was estimated at 26 %, although a marginal drop in absolute TEU figures handled was observed in 2016.



Source: Drewry Maritime Research, 2017.

Note: Data for 2017 and 2018 are projected figures.

Figure 2.18: Container port volume growth, 2016-2018

The 65% of World Volumes are performed by international operators, in Fig.2.19 are showed the 10 leading companies.

Looking to the volumes handled in Europe the total container throughput increased by 13.9% between pre-crisis year 2007 and 2016. But growth patterns differ per port region.

The top 15 ports (2.20) are performing much better than in 2016 (+2.1%) and 2015 (-1.6%). The top three recorded a growth of 4.3% in H1 2017 compared to 2% in 2016 and -1% in 2015.

Rank		Million 20-foot equivalent units	Share in world container port volumes (Percentage)	2014–2015 (Annual percentage change)
1	PSA International	53	7.7	-3.7
2	Hutchison Port Holdings	47	6.9	-0.1
3	DP World	37	5.4	3.3
4	APM Terminals	36	5.2	-3.0
5	China Merchants Port Holdings	26	3.8	2.0
6	China Ocean Shipping (Group)	20	3.0	1.8
7	Terminal Investment	18	2.7	9.2
8	China Shipping Terminal Development	9	1.3	13.5
9	Evergreen	8	1.1	-3.8
10	Eurogate	7	1.0	0.9

Source: UNCTAD secretariat calculations, based on data from Drewry Maritime Research, 2016a.

Note: Figures include total annual throughput for all terminals in which shareholdings held on 31 December 2015 were adjusted according to the extent of equity held in each terminal. Figures cover 2015, when China Ocean Shipping Liner (Group) Company and China Shipping Terminal Development were still separate companies (they merged in 2016).

Figure 2.19: Container port volume growth, 2016-2018

Rank 2016	Est. 2017	Port	2016 KTEU	H1 2017 % Growth
1	1	Rotterdam (NL)	12,385	9,30%
2	2	Antwerp (BE)	10,037	1,90%
3	3	Hamburg (DE)	8,91	0,00%
4	4	Bremerhaven (DE)	5,487	-4,90%
5	6	Algeciras (ES)	4,76	-9,40%
6	5	Valencia (ES)	4,733	-1,60%
7	7	Felixstowe (UK)	3,745	5,80%
8	8	Piraeus (EL)	3,675	3,80%
9	9	Marsaxlokk (MT)	3,08	N/A
10	11	Gioia Tauro (IT)	2,797	1,00%
11	12	Le Havre (FR)	2,519	7,80%
12	13	Genoa (IT)	2,298	13,30%
13	10	Barcelona (ES)	2,238	28,60%
14	15	Southampton (UK)	1,957	1,20%
15	14	Sines (PT)	1,513	34,00%

Figure 2.20: Containerized trade on major East-West trade routes, 2014-2017 (Million 20-foot equivalent units and annual percentage change)

Sines in Portugal continues to strengthen its position in the European container port

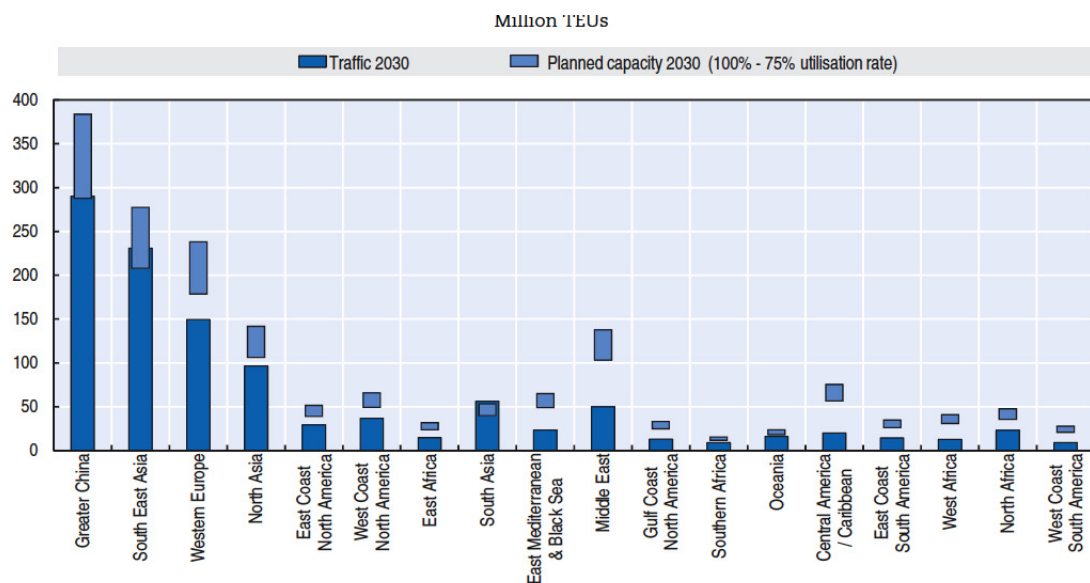
system with an impressive 34% growth in H1 2017. Barcelona, after the crisis of 2009, in 2017 seems to bring a trend break in the Catalanian port with an impressive 28.6% volume rise in H1. Also Genoa presents impressive growth figures, while Greek hub port Piraeus shows more moderate growth after a very steep volume rise in the past few years.

Europe's largest container port Rotterdam outperformed rivals with an impressive 9.3% TEU growth in H1 2017. Also Le Havre can look back at a strong first half year. Antwerp, a strong performer in 2015 and 2016 (i.e. +7.5% and +4% respectively), recorded a more modest 1.9% increase in the first half of this year. Hamburg's container throughput stagnated, while neighbouring Bremerhaven handled 4.9% less TEU in H1 2017.

The large differences in growth figures among individual ports are not only caused by differences in the economic situation of the hinterland regions served. The dynamics in the routing decisions of the large shipping alliances (2M, THE Alliance and Ocean Alliance) are having their full impact on the (larger) container ports, while port loyalty in the sea-sea transshipment market remains a loose concept ([96]).

Projected trade and freight flows to 2050 highlight the need to assess the capacity of existing national infrastructure such as port terminals, airports or road and rail infrastructure to deal with the bottlenecks that may emerge. The ITF study [77] shows, in figures 2.21 and 2.22, that the container traffic related to international trade could grow, under the high scenario, by 73% by 2030. This translates into over 1 billion TEU by 2030 and to nearly 2.2 billion TEU by 2050. Looking at the traffic by 2030, in relative terms, the largest capacity increases would be needed in South Asia (193%), Southeast (163%), North Africa (138%) and West Africa (137%).

There are already numerous plans for port expansion. The Global Container Terminal Operators from Drewry [56] forecast port capacity developments until 2025-30 based on announced expansions in the coming decade. Based on the estimated capacity developments up to 2030 it seems that there is sufficient capacity planned in most regions to accommodate future traffic growth. Several regions appear to have severely over planned capacity increases. Only in South Asia are projections for future freight are higher than the estimated capacity expansion for the region.



Source: ITF (2016b), *Capacity to Grow: Transport Infrastructure Needs for Future Trade Growth*, <http://dx.doi.org/10.1787/5jlwvz8jlpzp-en>.
 StatLink <http://dx.doi.org/10.1787/888933442592>

Figure 2.21: Traffic vs Capacity Growth by 2030

Sea area	Traffic 2013 MTEU	Traffic 2030 MTEU	Traffic 2050 MTEU	Estimated capacity 2013 MTEU	Planned capacity 2030 MTEU	Traffic – capacity 2030 MTEU
Greater China	196.4	290.0	494.1	248.3	383.8	-93.8
Southeast Asia	88.0	231.0	520.3	124.4	277.3	-46.3
Western Europe	97.8	149.4	257.5	168.1	238.2	-88.8
North Asia	43.0	96.5	146.0	70.9	141.6	-45.1
East Coast North America	23.9	29.1	34.7	42.4	51.7	-22.6
West Coast North America	24.9	36.8	32.2	43.2	65.5	-28.7
East Africa	8.2	14.6	46.2	13.0	31.9	-17.3
South Asia	19.2	56.2	143.8	29.1	53.1	3.1
East Mediterranean & Black Sea	16.8	23.6	50.7	27.5	65.1	-41.5
Middle East	36.7	50.0	108.4	50.9	137.6	-87.6
Gulf Coast North America	7.4	13.2	58.1	11.8	33.1	-19.9
Southern Africa	4.7	8.9	18.6	7.8	15.5	-6.6
Oceania	11.2	16.2	36.3	17.1	23.9	-7.7
Central America / Caribbean	19.6	20.2	58.5	29.5	75.4	-55.2
East Coast South America	13.2	14.3	28.8	19.0	35.0	-20.7
West Africa	5.4	12.8	36.6	8.8	40.9	-28.1
North Africa	9.8	23.3	87.0	13.2	47.4	-24.1
West Coast South America	7.9	9.2	19.3	14.0	27.8	-18.6
TOTAL	634.3	1095.2	2177.1	938.7	1744.9	-649.5

Note: MTEU stands for Million Twenty Foot Equivalent Unit.

Source: ITF (2016b), *Capacity to Grow: Transport Infrastructure Needs for Future Trade Growth*, <http://dx.doi.org/10.1787/5jlwvz8jlpzp-en>.

Figure 2.22: Container traffic by sea area in 2030 and 2050 and planned capacity 2030

2.2.3 Italian Port Container traffics: actual values and future trends

Looking closely to Italian reality, Italian ports are keynotes of the TEN-T network and inside the country two main sides can be distinguished:

- The north ports, located along the Adriatic Side, where the port of Trieste, is an important traffic links with Croatian ports as well as with Greece and Turkey. Along the Tyrrhenian side, the port of Genoa is the most important multi-traffic and transit node for international sea trade.
- The mediterranean ports, situated along the asset Suez- Gibraltar channel, million TEU provide the handling of containers from Far East to Europe, performing mostly transshipment activities. Port of Naples, along the Tyrrhenian side, is an important traffic and transit node form Mediterranean sea trade with the North Africa. The port of Gioia Tauro is a transshipment hub, located in the barycenter of the Mediterranean region, that attract transoceanic traffic and manage feeder services for the distribution in the medium short range.

Italian ports are governed by the Italian Port System Authorities and are organized into 15 Port System Authorities based in strategic decision-making centers based in the Italian "core" ports as set out by the EU. These are Genoa, La Spezia, Livorno, Civitavecchia, Cagliari, Napoli, Palermo, Augusta, Gioia Tauro, Taranto, Bari, Ancona, Ravenna, Venezia and Trieste. The new Port System Authorities will be in charge of 54 national ports. They are:

- Western Ligurian Sea: Genoa, Savona, and Vado Ligure (Savona);
- Eastern Ligurian Sea: La Spezia and Marina di Carrara (Massa e Carrara);
- Northern Tyrrhenian Sea: Leghorn, Piombino, Portoferraio, and Rio Marina (all 3 in Leghorn's province);
- North-Central Tyrrhenian Sea: Civitavecchia and Fiumicino (both in Rome's province), and Gaeta (Latina);
- Central Tyrrhenian Sea: Naples, Salerno, and Castellammare di Stabia (Naples);
The Strait (of Messina): Gioia Tauro (Reggio Calabria), Crotone (old and new ports), Corigliano Calabro (Cosenza), Taureana di Palmi and Villa San Giovanni (both in Reggio Calabria's province), Vibo Valentia, Reggio Calabria, Messina, Milazzo and Tremestieri (both in Messina's province);
- Sardinian Sea: Cagliari, Olbia, Porto Torres (Sassari), Golfo Aranci (Olbia-Tempio), Oristano, Portoscuso-Portovesme (Carbonia-Iglesias), and Santa Teresa di Gallura (only the commercial quay, in Olbia-Tempio's province);
- Western Sicilian Sea: Palermo, Termini Imerese (Palermo), Porto Empedocle (Agrigento), and Trapani;
- East Sicilian Sea: Augusta and Catania;

- Southern Adriatic Sea: Bari, Brindisi, Manfredonia (Foggia), Barletta, and Monopoli (Bari);
- Ionian Sea: Taranto;
- Central Adriatic Sea: Ancona, Falconara Marittima, Pescara, Pesaro, San Benedetto del Tronto (Ascoli Piceno, except the tourist quay), and Ortona (Chieti);
- North-Central Adriatic Sea: Ravenna;
- Northern Adriatic Sea: Venice and Chioggia (Venice); and, finally,
- Eastern Adriatic Sea: Trieste.

In Fig.2.23 volumes handled in the main Italian ports from 2006 to 2016 are reported.

	TEUs	TEUs	TEUs	TEUs	TEUs	TEUs	TEUs	TEUs	TEUs	TEUs
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
	numero	numero	numero	numero	numero	numero	numero	numero	numero	numero
Savona-Vado	227.197	242.720	252.837	196.317	196.434	170.427	75.282	77.859	85.311	98.033
Genova	1.657.113	1.855.026	1.766.605	1.533.627	1.758.858	1.847.102	2.064.806	1.988.013	2.172.944	2.242.902
La Spezia	1.136.664	1.187.040	1.246.139	1.046.063	1.285.155	1.307.274	1.247.218	1.300.432	1.303.017	1.300.442
Marina di Carrara	4.493	2.330	4.710	6.168	7.793	5.455	99	356	384	68
Livorno	657.592	745.557	778.864	592.050	628.489	637.798	549.047	559.180	577.470	780.874
Piombino	-	-	-	-	-	-	-	-	-	-
Civitavecchia	33.538	31.143	25.213	28.338	41.536	38.165	50.965	54.019	64.386	66.731
Napoli	444.982	460.812	481.521	515.868	534.694	526.768	546.818	477.020	431.682	438.280
Salerno	359.707	385.306	330.373	269.300	234.809	235.209	208.591	263.405	320.044	359.328
Gioia Tauro	2.938.176	3.445.337	3.467.824	2.857.440	2.852.264	2.304.987	2.721.108	3.094.254	2.969.802	2.546.805
Taranto	892.303	755.934	786.655	741.428	581.936	604.404	263.461	197.317	148.519	-
Brindisi	4.268	5.359	673	722	1.107	485	94	566	407	407
Bari	49	64	113	55	680	11.121	29.398	31.436	35.932	60.063
Ancona	76.458	87.193	119.104	105.503	110.395	120.674	142.213	152.394	164.882	178.476
Ravenna	162.052	206.786	214.324	185.022	183.577	215.336	208.152	226.692	222.548	244.813
Chioggia	-	-	-	-	-	-	-	-	-	-
Venezia	316.641	329.512	379.072	369.474	393.913	458.363	429.893	446.428	456.068	560.301
Portonogaro	46	-	-	-	40	-	40	-	-	-
Monfalcone	1.523	1.519	1.645	1.417	1.166	591	812	814	753	714
Trieste	220.310	265.863	335.943	276.957	281.643	393.186	408.023	458.597	506.019	501.222
Catania	16.372	22.504	18.036	21.791	20.560	17.659	22.087	30.255	33.162	49.595
Augusta	-	-	-	19	78	-	200	203	-	-
Palermo	27.234	31.767	32.708	30.111	33.495	28.568	22.784	20.647	14.344	12.896
Cagliari-Sarroch	687.657	547.336	307.527	736.984	629.340	603.236	627.609	702.143	717.016	748.647
TOTALE	9.864.375	10.609.108	10.549.886	9.514.654	9.777.962	9.526.808	9.618.700	10.082.030	10.224.690	10.190.597

Figure 2.23: Italian Ports volumes handled (TEU) from 2006 to 2016

Comparing the performance of Italian Gateways and Hubs throughput, over the past years, it appears that the former achieved better throughput figures.

Italian hubs recorded a 3% average yearly decrease when looking at 2007 to 2016. Put in absolute numbers, this means that Italian transshipment hubs handled a volume of 3.5 million TEU in 2016, whilst the pre-crisis throughput figure of 2007 amounted to 4.8 million TEU. This development corresponds to a decline of 26.5% when

comparing the figures of 2016 with those of 2007. In the Mediterranean, the main transshipment ports recorded a 3% increase in 2016.

Whilst hubs in Italy are dealing with declining throughput volumes, Italian gateways achieved an increase in cargo volumes of 19.1% 2016 versus 2007, in spite of the challenging market conditions. Almost 7 million TEU entered or left the country via one of the national gateways in the last year, compared to 5.9 % in 2007. However, when looking at 2016 in particular, the volume increase came in at only 1.2%. Looking at the new Italian ports governance reform, which reduced the port authorities from 26 to 15 port system authorities, we can observe some specific trends by analysing the figures of the last ten years.

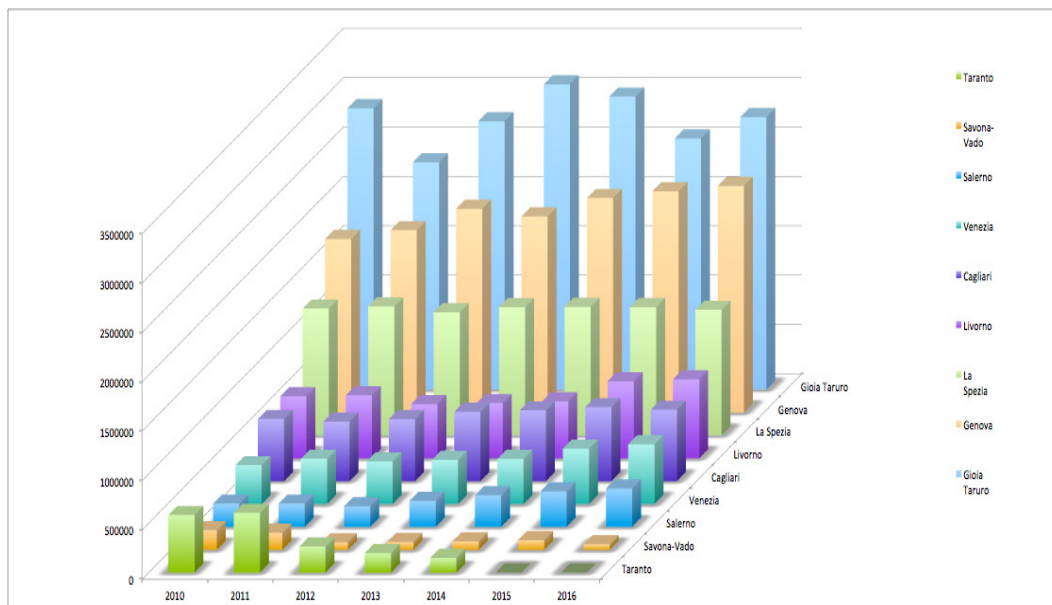


Figure 2.24: Italian Ports volumes trends (TEU) from 2006 to 2016

Looking at Fig.2.24 must be noted that, Gioia Tauro is the first port in terms of volumes handled, but being a transshipment hub, its throughput must be counted by half, making Genoa the principal gateway ports.

The Port of Genoa covers an area of about 700 hectares of land and 500 hectares on water, stretching for over 22 kilometres along the coastline, with 47 km of maritime ways and 30 km of operative quays. There are 4 main entrances:

- the Eastern inlet, affording access to the old port, to the shipyards, and to the terminals of Sampierdarena
- the Western (Cornigliano) inlet, used mostly by ships operating at the ILVA quays
- the Moltedo entrance, for ships operating in the oil terminals and to the Fincantieri shipyards

the Pra' entrance, at the western end of the port, for ships operating at the container terminal

In 2017, Genoa achieved a new record, handling 2,6 million of TEU with a growth of 13% compared to 2016.

Chapter 3

Optimal planning schemes for combining multiple truck trips in a seaport containerized environment

3.1 Problem description

3.1.1 The subject: truck carrier operators

In Italy the number of trucking companies is over 150 millions, 62 millions of which transport goods over long distances, while in the rest of Europe those numbers are significantly lower. In France 18 millions of road carrier companies are registered, 2 millions in Holland and only 900 in Germany. Reading these numbers, it could seem that the highest volumes of road freight flows are transported in Italy, but this is not a true fact. France, Germany and Holland share the 60-70% of the total amount of European traffics. More in detail, in Italy two typologies of road services could be distinguished: the so called “own account” and “third account” services. Belongs to the first typology the transport executed by physical or juridical persons, private or public, of every nature, that operate transportation operations to their own needs (art. 31 L. 298/74) and for which transport doesn’t represent the main economic activity but only a complementary activity. Complementary activities are realized if:

- Goods transported must be directly linked to the main activity of the company (i.e. fruit trader that transport fruits);
- Vehicles must be in line with the needs of the company (i.e. a small artisan cannot have 6 articulated cars);
- Costs of transport do not have to heavily affect over the total costs of the company;

- The transport must be made with a proper vehicle and driven personally by the owner or by one of his employees;

If one of these conditions is not respected the activity of transport could not be considered in “own account” but in “third account”(v. art. 88 CDS).

Otherwise, “third account” means the provision of a service performed in a professional and non-instrumental way to other activities, consisting in the transfer of goods by road by means of motor vehicles, after payment of a consideration. This activity is regulated by European Community with the regulation n. 1071/2009 and by law n. 35 del 04/04/2012 and successive disposition. Some peculiar characteristics are:

- Goods transported belong to a third subject, that is not the one that makes the transport;
- to have the license of transport who makes the transport must be enrolled in the official albo of trucking companies.

Traffic composition present the dominance of the “third account” over the “own account”.

The provision of services on behalf of third parties in the field of motor transport is subject to a mandatory tariff regime and the stipulation of contracts outside the legal limits is forbidden. The mandatory tariffs are different according to the type of goods delivered, the distance to be traveled and by weight classes, they are updated year by year by a decree of the Ministry of Transport. They are the sum of the actual transport, the time of the vehicle stop and the operations for the loading and unloading of the goods.

In the model phase we have based the set of the parameters on these tariffs.

Another element of distinction is the quantities of goods transported: “collet transport” and “full transport”. The first category is composed of little amount of goods from different senders to different recipients. They are organized in function of:

- Collection of packages at the buyer’s businesses;
- Charge, storage and discharge of goods;
- Transfer of goods by line trucks from main house to peripheral branches;

The full service is instead the transfer of an huge amount of homogeneous goods from one sender to one recipient. Usually the charge correspond to the maximum capacity of the vehicle.

In this Thesis the focus is on containerized transport and the main issue is the organization of the transport in order to maximize the vehicle capacity and routes.

3.1.2 Road Hinterland Connection Inefficiencies

Road haulage had the largest share of the modal split from the very start. It had three comparative advantages: it was flexible, as it could be hauled anywhere; it was fast, as truck transport did not need to be transshipped before reaching the final destination; and it was cheap over short distances. Speed did, however, become less important as the emphasis on regularity and reliability grew. Additionally, the introduction of the maritime container caused a shift of power from the trucker to the sea shipping company, with the former losing its old steady contacts, to the latter and the sea shipping company started to dictate the conditions. Moreover, instead of the customary prices per hour, the journey with a maritime container was paid by piece without the guarantee that the same company could transport more containers from the same ship. Furthermore, the task of the truck drivers was simplified as they no longer had to load or unload the trucks, which needed a lot of experience. The driver's only task, therefore, was to drive the truck between two points without even touching the contents of the container. This was a process that attracted new competition, whether from: the sea shipping companies, which could arrange their own transport; foreign truckers; and other modalities. While a train could transport a maximum of 80 TEU, a truck could carry two TEU, equating to one 40 foot or two 20 foot containers, but nowadays deep sea container ship has been able to easily carry as many as 18,000 TEU; at least 25 trains and approximately 3000 trucks were needed to transport to the hinterland the volumes of just one ocean going vessel. This cause the two majour issues of the truck transport: infrastructure congestion and pollution. Existing national infrastructure already faces issues of insufficient capacity in some regions of the world, especially in port cities. Projected trade flows to 2050 and the growing freight volumes highlight the need to assess the capacity of existing national infrastructure, making the rationalization of road transport an urgent need to be satisfied.

Nevertheless, the inefficiency of the vehicle utilization, explained in Section 1.1, makes the truck transport a sector with very low profits.

These considerations brought to the research question to find out a proper optimization model able to reduce planning inefficiencies, such as empty repositioning trips, in order to reduce costs and increase performance. To achieve this goal, is important the agreement of a multitude of truck carrier operators, because a large scale optimization can bring benefits not only to individual carrier operators but also the the entire community, reducing congestion and, as major positive consequence, pollutant emissions. This statement brings to the second research objective: consider the possibility to extend the optimization model proposed to a collaboration set of truck carrier operators, formulating a proper mechanism of profit share.

3.1.3 The considered network

A main feature of the considered network is the presence of maritime terminals (ports) and inland nodes (corresponding to companies, logistic platforms or dry ports) connected to ports by road connections. A transportation demand composed of a certain number of containers to be transferred between pairs of nodes has to be satisfied. This demand specifically refers to the demand mainly generated by a set of ports; in other words, we are here considering all the trips that include the import and export flows of containers in the inland basin of a set of ports. Moreover, some other container movements to be executed between inland terminals are also considered for the sake of completeness.

In order to further characterize the considered transportation activities, let us indicate with *trip* the movement realized by one vehicle between a pair of nodes. During a trip, the vehicle can be loaded with a full container (realizing what is called a full trip) or it can be loaded with an empty container (empty trip). Moreover, a trip can be further classified as:

- an *import trip*, corresponding to the case in which a full container has to be picked-up at a port and transferred to an inland node;
- an *export trip*, when a full container must be transported from an inland node to a port;
- an *inland trip*, with which a full container is transported from an inland node to another one.

In order to understand the problem properly, it is important to highlight the economic difference between loaded and empty flows. Loaded movements take place in response to customer requests, who bear transportation costs. Empty movements generate only costs and represent an unavoidable phase for the continuity of their activity. These empty flows occur for various reasons and, due to sakes of simplicity, major attention is devoted to the container based distribution of goods on behalf of customers. Typically a shipper, to meet the purposes of his/her industrial and commercial activities, requests shipping company to provide containers of a given type to his/her location on a specific day. Then one or more trucks pick up suitable containers from a location close to the shipper and move such an equipment to him/her. Once containers are loaded, they are put on trucks and moved to the destination. Afterward containers are loaded on appropriate vessels and moved through a series of intermediate ports to the destination port. Here they are unloaded and moved to the receiver using trucks or a combination of rail trains and trucks, according to the standard paradigm of door-to door service. Once the final destination has been reached, containers are unloaded and moved back either to a suitable depot, where they are stored while awaiting future requests, or immediately dispatched to a new shipper. Every profitable movement of a loaded container generates a non-

profitable empty movement, which is however essential for the continuing operations of shipping companies. Those trips are usually called "round trip" mode. This means that the truck has to perform both the productive trip and also the way back to its origin. This second part of the trip is ordinarily performed without a payload, so producing an unproductive empty trip. Round trips are very common mainly due to the competition between truck carriers/freight forwarders and shipping companies in the inland transport sector. In fact, even if in the "merchant haulage" mode - which is the case considered in this Thesis - truck carriers/freight forwarders are in charge of the inland transport organization, the decision of where to bring back the empty container is imposed by shipping companies that are the usual owners of containers. With the goal of dominating the inland transport sector, shipping companies usually oblige to bring back empty containers to the points where trips started, which may reduce profit margins for truck carriers.

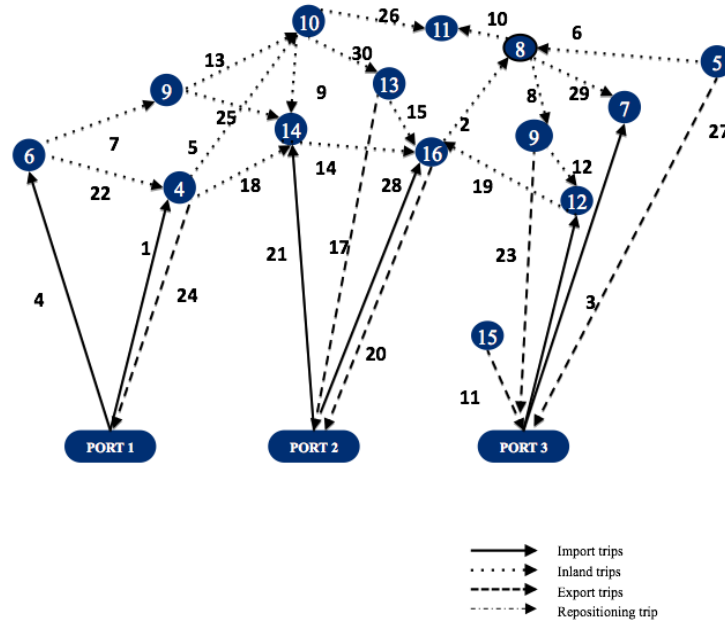


Figure 3.1: Sketch of the problem.

Figure 3.1 provides a sketch of the considered network type, composed of three ports and fourteen inland nodes. Import, export and inland trips demand are highlighted with different types of lines. Note that import and export trips may refer to different ports and that, in this particular "seaport-hinterland" context, import and export trips are usually longer than inland trips, which are typically executed to reposition containers or to satisfy a local demand. The idea is to combine, when possible, "round trips" avoiding empty ways back and reducing unproductive trips. The way it could be done will be better explained in 3.1.3.

The possibility of combining trips in such a way that they can be realized by the same vehicle in a sequence (route) is exploited in this section. To highlight the benefit of combining trips Fig. 3.2 shows - as an example - the difference between the case in which four trips are performed singularly (left-side) and the case in which they are performed in combination in the same route by using the same truck and the same load unit (right-side). In the left-side case, four empty trips are necessary to satisfy the whole demand, while in the right-side case the number of empty trips is reduced being it necessary to move the truck with an empty container only when destinations and origins of consecutive trips do not coincide (the trips devoted to transferring the truck with an empty container to the next node of the same route are also called *repositioning trips*). The necessity of repositioning containers is typically imposed by shipping companies. Note that, when the origin of the first trip and the destination of the last trip in a combination do not coincide but they refer to two different ports in which the shipping line has an empty depot, the repositioning activity can be avoided.

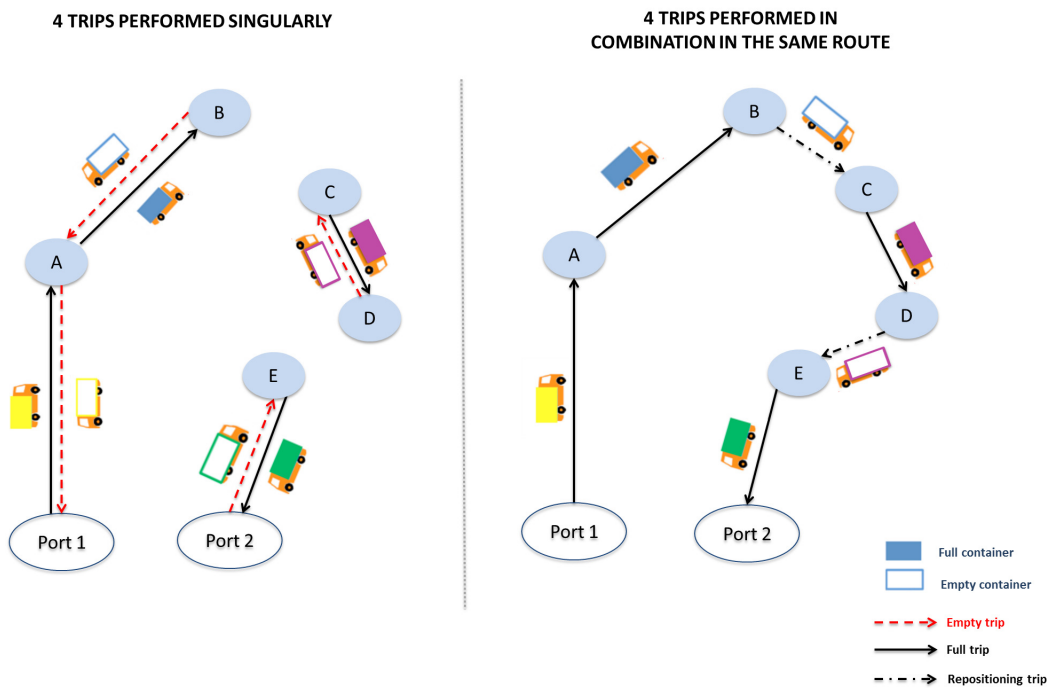


Figure 3.2: Four trips performed singularly (left side) versus four trips performed in combination (right side)

The combination of trips can be performed in two different ways: by using the same container or by adopting different containers. However, this only implies a different amount of time needed to perform the necessary activities in the logistic nodes. More clearly, if the same container is used, operations of stuffing and stripping of goods

have to be executed in the node whereas, if different load units are adopted, activities of loading and unloading the containers on and from trucks have to be performed. In this work the first case is considered but, by only changing the value of the time delay needed in the nodes for performing the specific operations, also the second case would be easily tackled.

As highlighted in Fig. 3.2, the combination of trips presents possible benefits. Nonetheless, in order to consider a certain trip combination, several operative aspects that may affect its feasibility or its effectiveness must be taken into account. In this work the following factors are explicitly considered:

- node time windows, related to both opening and closing times of terminals and companies. They have to be strictly respected (hard time constraints);
- trip due-dates which are usually imposed by (or agreed with) customers. They represent soft time constraints;
- cargo features to be taken into account when the same container is used for two subsequent trips. In fact, when using the same load unit for consecutive trips, the compatibility between the different goods which are the subjects of the trips must be checked and satisfied. Assuming that two trips are combined, the kind of goods transported in the first trip cannot be, as instance, dirtier than the goods that have to be transported during the second trip (e.g. the sequence t-shirts and animal feed is admitted, but not viceversa);
- European (EU) driving rules, which have to be strictly respected by truck drivers. This affects the total operative time available and, also, the number of truck drivers needed.

It is to be noted that trip due-dates can be violated, but in case this happens, delay costs must be considered. These cost terms assume a different meaning when referring to import, inland or export trips. In the first two cases delay costs refer to eventual fines to be paid to companies or inland nodes for not respecting imposed (or agreed) due-dates for picking-up or delivering containers. In case of export trips, delay costs are related to “change of vessel” fees to be paid to seaport terminal operators for replanning containers on the next ships.

With reference to the cargo compatibility to be fulfilled when the same container is used, this typically refers to the “cleanness” of goods. This means that trips can be matched according to a criticality index associated with the transported goods. A criticality index with a value equal to “1” corresponds to a high level of dirtiness or toxicity of goods, determining that the container cannot be reused for another trip (unless a specific treatment is made, which is not here considered). A value equal to “2” indicates the presence of goods which make the container reusable only in some specific cases; finally, a value equal to “3” means that the container can be reused without any treatment. For instance, the combination of four trips with criticality indexes 3-2-2-2 is allowed because the level of dirt increases from

3 (meaning “clean”) to 2 (“dirty”) and then it does not change. The case 3-2-2-3, instead, is not permitted because the third and forth trip are not compatible.

When considering a combination of four trips, the allowable sequences of criticality indexes are listed in Table 3.1.

Table 3.1: Allowable sequences of the criticality index

Two Comb.	Three Comb.	Four Comb.
3-3	3-3-3	3-3-3-3
3-2	3-3-2	3-3-3-2
2-2	3-2-2	3-3-2-2
2-1	3-2-1	3-2-2-2
1-1	3-1-1	3-2-2-1
-	2-2-2	3-2-1-1
-	2-2-1	3-1-1-1
-	2-1-1	2-2-2-2
-	1-1-1	2-2-2-1
-	-	2-2-1-1
-	-	2-1-1-1
-	-	1-1-1-1

Finally, regarding European driving rules, according to the European Regulation 3820/85, specific constraints regarding working times, breaks and rest periods for drivers have to be respected when planning truck routes. Since the planning approach proposed is daily based, only daily restrictions are taken into account. These rules define the maximum legal daily and weekly driving hours, and the management of breaks, as follows:

- during a working day, after 4.5 consecutive hours of driving, the driver has to take a break not smaller than 45 minutes. During this rest period the driver is not allowed to drive nor to undertake any other working activity;
- during a working day, the maximum driving period is equal to 9 hours, after which a driver shall take a daily rest of at least 11 hours, during which he may freely dispose of his time.

The presence of the above mentioned driving rules has to be explicitly considered because they affect the number of drivers needed to perform a certain sequence of trips and, then, a certain combination. As a matter of fact, when the time needed to perform a trip combination requires the activity of several drivers, a cost is obviously incurred. Table 3.2 shows the number of drivers needed on average over an horizon of one day to fulfil the EU driving hour constraints.

Table 3.2: Number of drivers needed according to number of trips in a combination.

# of trips combined	# of drivers
2	1
3	1
4	1
5	2
6	2
7	3

By looking at Table 3.2, it can be observed that, considering one working day and a single driver, it is difficult to combine more than four trips in a single route because the trips due-dates and the other time constraints would be probably violated, thus causing high delay costs that would neutralize the convenience of combining trips.

3.2 Literature Review on Multiple Trip Combination

As also pointed out in [72], in the last few years a growing attention has been placed on problems related to multiple trip optimization and routing. This is due to the numerous application contexts (such as maritime transportation, city logistics distribution, road inland transportation or inventory routing) of such problems.

Table 3.3: Literature on MTRVP problems: main features, considered extensions and adopted solution methods

Author	Year	VRP	Multiple trips	Depot	TW	Service dep. load. times	Limited trip duration	EU driv. hours	Trip due to dates	Cargo features	Solution method
[70]	2016		x		x				x		Exact
[9]	2002	x	x	x	x		x				Heuristics
[2]	1990	x	x								Heuristics (sav. algorithm)
[3]	1996	x	x			x					Heuristics (tabu search)
[5]	1998	x	x		x			x			Heuristic (tabu search)
[6]	1999	x	x		x	x	x		x		Heuristic (different search approach)
[7]	2000	x	x	x			x				Four heuristic algorithms
[8]	2002	x	x	x			x	x	x		Heuristic (genetic algorithms)
[11]	2004	x	x	x							Heuristic (genetic algorithms)
[14]	2006	x	x		x	x	x				Heuristic (Large Neighbourhood Search (LNS))
[15]	2006	x	x			x		x			Mixed integer program+consolidation algorithm
[16]	2006	x			x			x			Heuristic (Large Neighbourhood Search (LNS))
[18]	2007	x	x		x			x			Exact
[19]	2007	x	x	x			x				Heuristic (tabu search)
[20]	2007	x									Heuristic
[21]	2007	x	x	x			x				Heuristic (genetic algorithms)
[23]	2008	x	x	x		x					Heuristic (tabu search)
[24]	2008	x		x						x	Dynamic algorithm
[25]	2008	x	x	x			x				Exact (column generation)
[28]	2009	x	x	x	x		x			x	Heuristic (an adaptive guidance mechanism)
[29]	2010	x	x	x	x	x	x	x			Exact
[32]	2011	x	x	x	x	x	x				Exact (pseudo polynomial model)
[34]	2011	x	x	x			x				Exact (branch and cut algorithm)
[35]	2011	x		x	x	x		x			Insertion construction heuristic
[33]	2011	x	x		x	x	x	x			Heuristic (metaheuristic)
[37]	2013	x	x	x	x			x			Adaptive Large Neighbourhood Search (ALNS) metaheuristic
[38]	2013	x	x	x	x						Exact (branch and price algorithm)
[46]	2013	x	x	x	x	x					Exact (branch and price algorithm)
[42]	2013	x	x	x				x			Memetic algorithm
[47]	2014	x	x	x	x	x	x		x		Exact
[48]	2014	x	x	x	x		x			x	Heuristic (genetic algorithms)
[52]	2014	x	x	x	x	x	x				Heuristic (adaptive memory procedure paradigm)
[53]	2014	x	x	x	x	x	x				Heuristic (Adaptive Large Neighbourhood Search (ALNS))
[54]	2014	x	x	x	x	x	x	x			Heuristic (two constructive heuristic by local search)
[72]	2016	x	x		x	x	x				Heuristic (Adaptive heuristic dominance)
[83]	2017	x		x	x			x			Exact
[84]	2017	x	x	x							Exact

Table 3.3 ([70], [9], [2], [3], [5], [6], [7], [8], [11], [14], [15], [16], [18], [19], [20], [21], [23], [24], [25], [28], [29], [32], [34], [35], [33], [37], [38], [46], [42], [47], [48], [52], [53], [54], [73], [83], [84]) provides a non comprehensive overview of the papers available in the literature regarding the *Multi-Trip Vehicle Routing problems (MTRVPs)*. Most of the papers are also included in the recent survey [72], where mathematical formulations as well as exact and heuristic approaches are provided, together with the main variants for this problem and its areas of application.

Table 3.3 presents several approaches for the MTRVP and, for each approach, the table highlights the main features related to some specific requirements. More specifically, the aspects considered in Table 3.3 regard the presence of:

- Time Windows (TW column) related to opening and closing times of network points (as instance terminals and companies);

- Service dependent loading times, i.e., the cases in which the loading time of a vehicle at the first network point depends on the customers visited during the trip;
- Limited trip durations, arising when each trip can have a maximum time duration;
- European driving hour rules, that are rules governing the drivers' behaviour;
- Trip due-dates;
- Cargo features constraints, related to the typology of goods than can be transported in the different containers.

The last column of Table 3.3 reports which kind of solution approach for the considered planning problem has been proposed in the corresponding paper.

It can be noticed that, in the last years, the presence of time windows is a feature of an increasing number of the available papers whereas other features, such as service dependent loading times and limited trip durations, are rarely addressed. A very limited number of papers considers EU driving hour constraints, and even a smaller number of works takes into account trip due-dates and cargo features. Regarding the adopted solution method, most of the problems have been faced with heuristic approaches, as also highlighted in [72].

Even though a clear increase in the number of contributions in multiple trips optimization can be observed in the recent years, the literature on MTVRP is still partial and further investigation is required to take into account new operative requirements and bigger instances of the problem.

Other aspects considered in MTVRPs regard the capacity of vehicles (see for instance [9]), the presence of heterogeneous fleets or the evaluation of CO_2 emissions as done in [59]. Moreover, [45] and [117] address the multiple combinations of trips and empty containers on the same truck considering the transportation of up to two 20-feet or one 40-feet container on a truck.

As regards the solution methods proposed, [2] had, as first, treated the multiple trips combination problem, through a saving based method and a bin packing heuristic. In [3] Eric et al. allocated vehicles with a bin packing heuristic after having constructed a set of possible routes generated by a Tabu Search method. [4] and [13] applied an adaptive memory heuristic with a minmax and a minimization cost objective, respectively. More specifically, in order to reduce unnecessary traffic flow, most works in the field attempt to combine pick-up and delivery trips together to reduce empty movements of containers [43]. These studies are then extended to the cases that further merging the route with inland deliveries [51], and/or considering the usage of dual-carriage trucks [62]. No matter what specific context is considered, almost all previous studies base their discussions around the general Mixed Integer Programming (MIP) model for the Vehicle Routing Problem with Simultaneous

Pickups and Deliveries and Time Windows (VRPSPDTW), which is originally designed in generic vehicle routing literature [44].

As underlined by [83], those models produce optimal solutions that tells which link should be travelled by which truck, but are limited to the cases where a number of individual trips are combinable to form a single delivery/pick-up route and not always valide for container delivery since the latter normally just allows the combination of no more than two (import only) or four (import and export) trips in one return route due to the capacity of vehicle (dual-carriage). On the other hand, as in the VRP-SPDTW model, one has to start from transforming the demand graph into one with a distinct node for every single task, the number of nodes and links are largely increased which improves the difficulty of solving the problem, and therefore makes the solution only available via heuristics.

Other recent works, inspired by real life cases, combined multiple trip routes with time windows and vehicle capacity constraints, such as the one presented in [30] where a heuristic approach for determining pick up and delivery sequences for daily operations with the goal of minimizing transportation costs is proposed. Azi et al. ([18]) developed an exact column generation approach for a single vehicle considering time windows and then extended this work to the multiple vehicle case [29]. Vidovic et al. ([36]) solved the problem when pick up and delivery nodes may be visited only during predefined time intervals. Authors solved the problem of trip combination as a multiple assignment model, with a commercial software thanks to the small dimension of the variables indexes, that is four in case of dual-carriage or two if the truck can carry only one container at voyage.

Recently the problem was studied in [40], where a Tabu Search meta heuristic for the time dependent and multi-zone multi-trip vehicle routing problem with time windows is presented. Other meta-heuristics are proposed by [41] where the total operating time of all trucks is minimized respecting hard time constraints, and by [42] where the trips combination problem is solved with a local search procedure. Time windows have also considered in [63] where two branch-and price frameworks based on two set covering formulations are proposed. [64] solved the same problem by applying a Tabu Search algorithm. In all the works above cited, EU driving time regulations are not taken into account.

In [33] Derigs et al. presented two heuristic approaches for road feeder services devoted to air cargo in which driving hours constraints are strictly considered to combine multiple trips with the same tractor. In [71] a solution of a multiple trips door-to-door service for picking and delivering customers to the airport (MTM-D2PDCA) is proposed and solved by using a three-phase exact algorithm.

In [50], an optimization approach devoted to combine trips two by two in a cooperative environment among different carriers is proposed, whereas [45] and [49] address the multiple combinations of trips and empty containers on the same truck

considering the transportation of up to two 20-foot or one 40-foot container on a truck.

Driving hours and traffic congestion are considered in [34], where an integer linear problem that minimizes the total duty time is formulated. In [31] the problem of scheduling working hours of team drivers in European road freight transport is studied. The problem of visiting a sequence of locations within given time windows is solved by applying a depth-first-breadth-second search method which can find a feasible schedule complying with standard daily driving time limits. In [83] the work of [36] is extended considering more realistic restrictions such as the working hours restrictions for drivers, the ready time of containers at and/or the expected departure from ports and the possibility of having some containers with multiple customer locations as its receivers. The model formulated is a MILP and has been tested over some numerical examples without any heuristics.

Summarizing, although the combination of trips is very useful, the number of scientific approaches dealing with this critical issue is not very high and, as previously pointed out, most of them solve this problem by using heuristic techniques.

3.3 Thesis main contribution in multiple trip combination

The contribution of this Thesis in the multiple trip combination problem follows:

- compared with the classical VRP formulations presented in 3.2, where couple of trips are considered, a more compact and clear formulation is proposed, since all the possible trips belonging to a combination are considered;
- the context analyzed is the one related to seaports and their connection with the hinterland. This context is characterized by the presence of import and export trips (typically being long-distance trips mainly related to the need of fulfilling a demand of full containers) and inland trips (typically having a shorter distance to be covered and mainly dedicated to repositioning trips). This is a specific feature of the considered case study giving rise to some features of the planning problem that will be described in the next section;
- a different objective function is provided in comparison with the classical MTVRP formulation. This latter minimizes the total traveling cost covered by vehicles, whereas in this work the cost saving obtained when performing trips in combination instead of singularly is minimized;
- time windows and service times in nodes are considered such as in some variants of the MTVRP (see, for instance, [32], [47], [52], [53], [73]);
- important operative aspects such as goods compatibility, trip due-dates and driving hour rules, which are often neglected by the papers in the literature, are here considered;
- truck depots are not considered. It must be noted that the majority of papers regarding MTVRP takes into account depots. The specificity of the network here addressed (as it will be explained in the following section) makes it possible to neglect the presence of depots;
- trucks capacities are not considered since each trip is referred to a container to be moved between an origin and a destination, and not to boxes or other freight type to be filled in a truck. This aspect is also considered in the Rollon - Rolloff Vehicle Routing Problem (RRVRP) [7]. Both in our problem and in the RRVRP only one cargo unit (container or trailer) is considered at a time, all trucks (or tractors) are identical, the length of each truck (or trailer) workday is fixed, each truck (or trailer) route involves multiple trips, and service time is considered. However, the work [7] does not take into account node time windows, cargo features and EU driving times.

All the above mentioned differences motivate the decision of defining an ad-hoc modeling approach for the problem under investigation, instead of adopting existing models that would not adequately fit the problem characteristics. This approach has

been formulated and published in [60] and in [61], in which trips were combined in fixed combinations of three trips each with the goal of maximizing the carrier cost saving, and in [69] , [86] where trips, belonging to different carriers are shared with the goal of maximizing carrier profits, as will be further explained in Chapter 4.

Moreover, the present Thesis formulates and compares different optimization schemes for combining multiple trips with the goal of determining the most efficient trip combination in order to maximize the total cost saving of a road carrier. More specifically, the following alternatives for combining trips are defined and compared:

- *fixed size scheme*. In this approach trips are combined in pre-fixed size combinations, i.e. in combinations composed only of 4 (*four by four*), 3 (*three by three*) or 2 (*two by two*) trips respectively;
- *sequential scheme*. In this scheme three optimization models are solved in sequence: initially, a first problem combines trips *four by four*, then the second matches the remaining trips in *three by three* combinations and, finally, the third problem combines the residual trips *two by two*;
- *variable size scheme*. In this scheme a single optimization model combining at the same time all the trips in different-sized combinations is applied.

3.4 Optimization Schemes for multiple trip combination

The optimization approach aimed at finding the best combinations of road trips in a containerized transportation network as the one presented in Section 3.1.3 is detailed in the present section. Three optimization schemes are proposed, named *fixed size scheme*, *sequential scheme* and *variable size scheme*.

The first optimization scheme studied during the three years of PhD has been the *fixed-size scheme*. By this scheme trips combinations composed of a fixed number of trips are taken into account. This means that trips are combined two by two, three by three or four by four as reported in Fig. 3.3 for the three by three case (the two by two and four by four cases are analogous). In the following, fixed size combinations will be denoted as *fixed-2 scheme* in the case in which trips are combined two by two, *fixed-3 scheme*, and *fixed-4 scheme* when three by three and four by four combinations are adopted, respectively.

It should be noted that in most cases real operators do not face the problem of combining trips, especially when they operate in small-medium sized enterprises. The most efficient real situation that is encountered refers to some carriers grouping trips two by two (which means a *fixed size scheme*) when planning their activities. At the best of our knowledge, the three by three and four by four cases are almost never adopted in real cases but they have been considered in this thesis in order to introduce new combinations and to evaluate the corresponding performance.

After, followed the optimization scheme *sequential scheme*, where, instead, three phases are sequentially executed. First, all combinations of 4 trips are determined, then, the remaining set of trips is considered in order to find the best 3 by 3 combinations. Finally, the remaining trips are combined 2 by 2. The three phases are shown in Fig.3.4.

In the *sequential scheme*, instead, trips are combined in three phases in a sequential way. First, all combinations of 4 trips are determined, then, the remaining set of trips is considered in order to find the best three by three combinations. Finally, the remaining trips are possibly combined two by two. These three phases are shown in Fig.3.4.

Finally, in the *variable size scheme* the best combinations with variable size (i.e., different number of trips in each combination) are computed all at once over the whole set of trips, as depicted in Fig. 3.5. Again, it can be noted that the *sequential scheme* and the *variable size scheme* have not yet been adopted by real operators. They are defined and analyzed in this thesis in order to evaluate their performance.

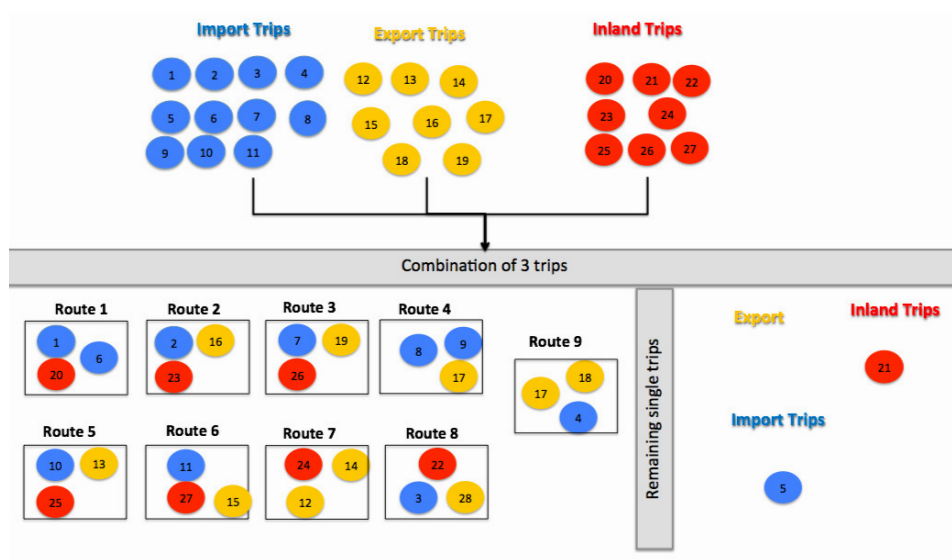


Figure 3.3: Optimization scheme of the *fixed size* approach for three by three combinations

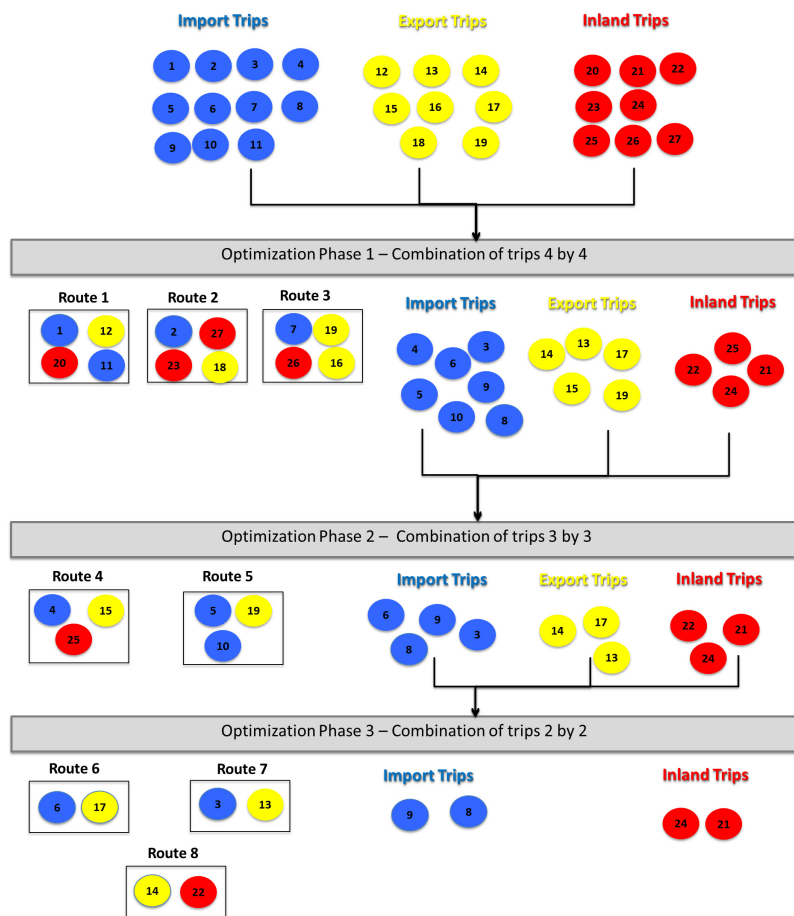


Figure 3.4: Optimization scheme of the *sequential* approach

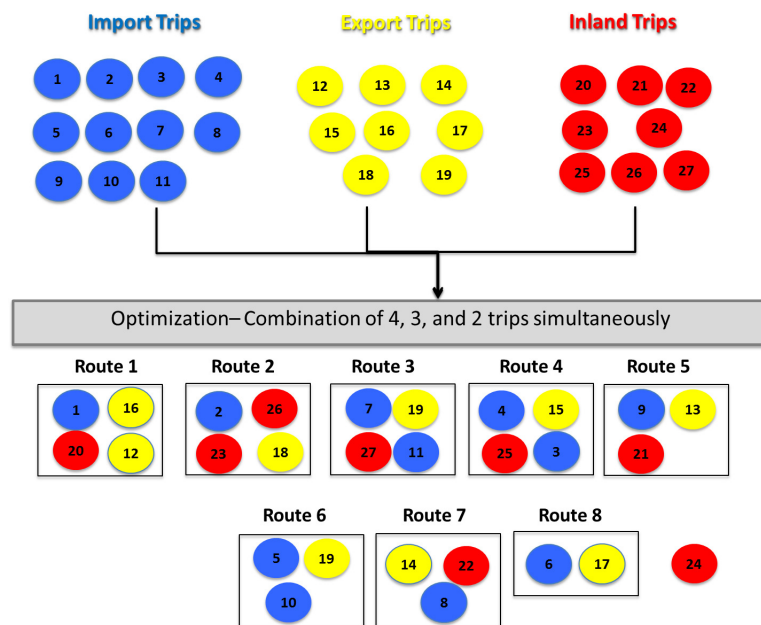


Figure 3.5: Optimization scheme of the *variable size* approach

3.4.1 The mathematical model

The model used in all the optimization schemes to determine the best combinations of trips in the considered road network is stated in the following. The transportation network is represented as a graph $G = (V, A)$, where V is the set of nodes and A the set of links. Nodes are the points of origin and destination of trips (corresponding to companies, ports, dry ports or logistic platforms), whereas a link is the shortest path that connects two nodes.

The following notation is adopted:

- T is the set of trips;
- c_u is the unitary transportation cost (expressed in euro/km);
- $d_i, i \in T$, is the travelled distance related to trip i ;
- $t_i, i \in T$, is the travel time necessary for executing trip i . It depends on the distance d_i and the average speed v of a generic truck: $t_i = \frac{d_i}{v}$;
- $h_i, i \in T$, is the due-date of trip i , which is always assumed to be respected if trip i is realized as a single trip;
- $r_i, i \in T$, is the release time of trip i , that is the time in which the trip is available to be executed;
- $q_i, i \in T$, is the starting time of trip i ; it is assumed to coincide with the release time of the trip if the trip is executed singularly and for the first trip of any combination;
- $f_i, i \in T$, is the finishing time of trip i . It coincides with its due-date h_i if trip i is realized as a single trip;
- $\epsilon_{il}, i, l \in T$, is the distance between the destination of trip i and the origin of trip l . This is the distance to be covered by a vehicle if trips i and l are executed consecutively, in which case the vehicle has to cover such a distance loaded with an empty container (i.e., with an empty trip). Of course, $\epsilon_{il} = 0$ if the destination of trip i coincides with the origin of trip l ;
- $C_i, i \in T$, is the cost for realizing trip i singularly. It is given by equation (3.1):

$$C_i = 2c_u d_i, i \in T \quad (3.1)$$

The following notation is further introduced to consider time windows and driving hours constraints:

- a is a parameter that takes into account the maximum number of daily driving hours allowed by European regulation, i.e. 9 hours;
- s is the service time needed in each node for stuffing/unstuffing goods in a container (or loading/ unloading container when using different containers in a route);

- λ is the duration of a break when the limit of 4.5 hours of consecutive driving is reached. λ is set equal to 45 minutes.
- $O_i, \hat{O}_i, i \in T$, are respectively the opening and closing time of the starting node of trip i ;
- $D_i, \hat{D}_i, i \in T$, are respectively the opening and closing time of the destination node of trip i ;
- c_d is the unitary cost of delay (expressed in euro/h).

The set \mathcal{C} is the set of all possible trip combinations. Set \mathcal{C} depends on the considered optimization scheme. In the fixed-2 scheme in which trips are combined two by two, $\mathcal{C} = \mathcal{C}_2 \in (T \times T)$, whereas it is $\mathcal{C} = \mathcal{C}_3 \in (T \times T \times T)$ and $\mathcal{C} = \mathcal{C}_4 \in (T \times T \times T \times T)$ in the three by three and four by four *fixed size* schemes, respectively. Moreover, in the *sequential* scheme, set \mathcal{C} is varied in the three steps of the procedure as it will be described later on. Finally, the set $\mathcal{C} = \mathcal{C}_v \in (T \times T \times T \times T) \cup (T \times T \times T) \cup (T \times T)$ is adopted for the *variable size* scheme. It is important to note that each element of set \mathcal{C} , i.e., each combination of trips, also defines the order in which trips are executed.

The following further notation is necessary:

- $l(c), c \in \mathcal{C}$ is the number of elements in the generic combination c (obviously it is $l(c) = 2, \forall c \in \mathcal{C}_2, l(c) = 3, \forall c \in \mathcal{C}_3, l(c) = 4, \forall c \in \mathcal{C}_4$);
- L is the maximum number of trips in a combination, that in our case is 4;
- $w(i, c), i \in T, c \in \mathcal{C}$, is a function that takes on value equal to 1 if trip i is included in combination c , 0 otherwise;
- $v_i(c), c \in \mathcal{C}, i \in T$, is a function that identifies the index of the i -th trip in trip combination c ; note that the function returns a value equal to 0 if the i -th trip does not belong to the considered combination;
- $\tau_{\text{tot}}(c), c \in \mathcal{C}$, is the total time for executing combination c ;
- $b_c, c \in \mathcal{C}$, is the number of breaks allowed for combination c . It is introduced in order to take into account EU driving hours restriction (i.e. a break must be performed after 4.5 hours of driving);
- $g_c, c \in \mathcal{C}$, is a binary parameter that assumes value equal to 1 if it is possible to combine the trips belonging to combination c in function of their goods characteristics (i.e. their level of cleanness);
- $C_c, c \in \mathcal{C}$, is the cost for serving combination c . Note that such cost includes transportation costs and possible delay costs to be taken into account when realizing the considered trip combination.

As regards the timing of trips, it has already been specified that the starting time of a trip which is executed singularly coincides with the release time of the trip and the same happens for the first trip of any combination. Then, the starting times of single trips and the starting times of the trip combinations are actually a-priori given.

Moreover, the finishing times of single trips are assumed to be coincident with the trips due-dates and also these times are not matter of decision. Still it is necessary to define the starting times of all the trips belonging to a combination, apart from the first one, and the finishing times of all trips included in a combination.

The following expressions provide the computation of finishing times:

$$f_{v_i(c)} = q_{v_i(c)} + t_{v_i(c)} + b_c \lambda \quad c \in \mathcal{C}, \quad i = 1, \dots, l(c) \quad (3.2)$$

Once determined the finishing time of the last trip in a given combination, the overall time necessary for executing the combination can be computed as follows

$$\tau_{\text{tot}}(c) = f_{v_{l(c)}(c)} + \epsilon_{v_{l(c)}(c), v_1(c)} \quad c \in \mathcal{C} \quad (3.3)$$

The above time also includes a possible repositioning trip to be executed after the last trip in a combination to bring the empty container back to the origin of the first trip of the combination. It must be noted that, as already described in Section 3.1.3, whenever the first trip of a combination starts in a port and the last trip of the same combination is again a port, it can happen that no repositioning is necessary if the shipping line has an empty depot in both ports, so allowing to leave the container indifferently in one of the two.

Starting times must, instead, be defined in such a way that possible repositioning trips are considered and the correct sequencing of trips inside the combination is guaranteed. This is done by fulfilling the following relations

$$q_{v_{i+1}}(c) = t_{v_i(c)} + \epsilon_{v_i(c), v_{i+1}(c)} \quad c \in \mathcal{C}, \quad i = 1, \dots, l(c) - 1 \quad (3.4)$$

Figure 3.6 provides a sketch of the proposed time window framework in which, in the upper diagram, the timing of four not combined trips is reported whereas, in the lower diagram, the same timing is depicted when trips are combined. It can be noticed that, when trips are not combined (upper diagram), hard time windows related to opening and closing times of nodes are respected, as well as trip deadlines which are assumed to coincide with trip finishing times (in other words, trips are performed so that their finishing times exactly correspond to their deadlines). However, when trips are combined (lower diagram), apart from the first trip (whose finishing time is always supposed to fulfil the deadline), it may happen that some constraints are violated. If a hard time constraint, such as the opening time of the origin node of trip l , is not respected, the combination cannot be performed; on the contrary, if a soft time window constraint is violated, such as the deadline of trip l , a delay cost has to be paid. In other words, coupling trips can delay some trips (apart the first one) with the consequence that the related deadlines h_k are no more respected.

The decision variables of the problem are:

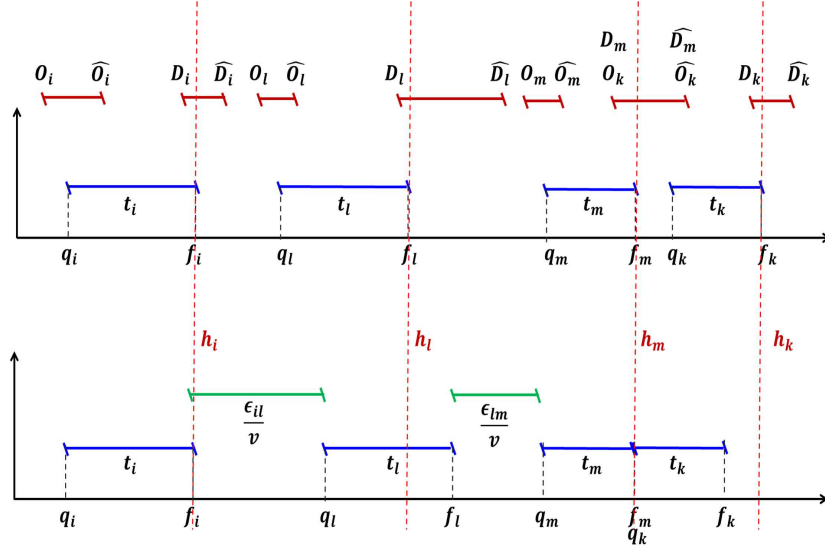


Figure 3.6: The time window framework in case of 4 trips.

- y_c , $c \in \mathcal{C}$, binary variables assuming value equal to 1 if trip combination c is chosen;
- x_i , $i \in T$, binary variables assuming value equal to 1 if trip i is performed singularly.

As already mentioned, the considered cost function refers to the cost saving that carriers obtain by executing trip combinations instead of single trips. The cost saving is determined as the difference between the cost for executing all trips singularly and the cost associated with the best combination of single trips and trips combinations. In order to compute the cost saving it is necessary to determine the cost for realizing a generic trip combination c , $c \in \mathcal{C}$; such cost is given by

$$C_c = \left[\left(\sum_{i=1}^{l(c)} c_u d_{v_i(c)} \right) + \left(\sum_{i=1}^{l(c)-1} \epsilon_{v_i(c), v_{i+1}(c)} + \epsilon_{v_{l(c)}(c), v_1(c)} \right) + \left(\sum_{i=1}^{l(c)} c_d \max\{f_{v_i(c)} - h_{v_i(c)}, 0\} \right) \right] \quad c \in \mathcal{C} \quad (3.5)$$

Three terms compose the above expression of cost C_c : the first term is the transportation cost necessary for executing all the trips in the combination. The second part of the cost refers to the cost of possible repositioning trips to be executed between consecutive trips and the last term of (3.5) takes into account delay costs.

The third term in C_c induces a nonlinearity which is tackled in the problem statement by considering two sets of linear constraints in place of (3.5).

The problem formulation follows.

Problem 1. Find the optimal values of y_c , $c \in \mathcal{C}$ and x_i , maximizing the cost function

$$\sum_{i \in T} C_i(1 - x_i) - \sum_{c \in \mathcal{C}} C_c y_c \quad (3.6)$$

subject to (3.2), (3.3) and

$$C_c \geq \left[\left(\sum_{i=1}^{l(c)} c_u d_{v_i(c)} \right) + \left(\sum_{i=1}^{l(c)-1} \epsilon_{v_i(c), v_{i+1}(c)} + \epsilon_{v_{l(c)}(c), v_1(c)} \right) + \left(\sum_{i=1}^{l(c)} c_d (f_{v_i(c)} - h_{v_i(c)}) \right) \right] \quad c \in \mathcal{C} \quad (3.7)$$

$$C_c \geq \left[\left(\sum_{i=1}^{l(c)} c_u d_{v_i(c)} \right) + \left(\sum_{i=1}^{l(c)-1} \epsilon_{v_i(c), v_{i+1}(c)} + \epsilon_{v_{l(c)}(c), v_1(c)} \right) \right] \quad c \in \mathcal{C} \quad (3.8)$$

$$x_i + \sum_{c \in \mathcal{C}: w(i,c)=1} y_c = 1 \quad i \in T \quad (3.9)$$

$$0 \leq (q_{v_i(c)} - O_{v_i(c)}) y_c \leq \hat{O}_{v_i(c)} y_c \quad c \in \mathcal{C}, i = 2, \dots, l(c) \quad (3.10)$$

$$0 \leq (f_{v_i(c)} - D_{v_i(c)}) y_c \leq \hat{D}_{v_i(c)} y_c \quad c \in \mathcal{C}, i = 1, \dots, l(c) \quad (3.11)$$

$$y_c \leq g_c \quad c \in \mathcal{C} \quad (3.12)$$

$$b_c y_c \leq 1 \quad c \in \mathcal{C} \quad (3.13)$$

$$\tau_{\text{tot}}(c) y_c \leq a \quad c \in \mathcal{C} \quad (3.14)$$

$$y_c \in (0, 1) \quad c \in \mathcal{C} \quad (3.15)$$

$$x_i \in (0, 1) \quad i \in T \quad (3.16)$$

$$f_{v_i(c)} \geq 0 \quad c \in \mathcal{C}, i = 1, \dots, l(c) \quad (3.17)$$

$$q_{v_i(c)} \geq 0 \quad c \in \mathcal{C}, i = 2, \dots, l(c) \quad (3.18)$$

□

The resulting problem is a MILP (Mixed Integer Linear Programming) problem in which the objective function (3.6) is the sum of the cost savings obtained by performing trips in all the combination types allowed, instead of singularly. Constraints (3.7) and (3.8) are used to define the expression of the cost C_c as in (3.5). Constraints (5.5) ensure that each trip is performed, either singularly or in a combination. Constraints (3.10) and (3.11) refer to the presence of opening and closing time windows of nodes.

Constraints (3.12) guarantee that only combinations in which the criticality indices of trips are compatible are chosen, while constraints (3.13) ensure that no more than one break is executed during a route in order not to overcome the maximum daily driving hours. Moreover, constraints (5.6) check that the time required by a truck for performing a combination does not exceed the total time availability of the truck. Finally, constraints (3.15)÷(3.18) define the nature of the decision variables included in the problem.

3.5 Experimental results

An experimental campaign based on real data has been carried out to validate the efficacy of the proposed optimization schemes.

The models have been implemented in Visual Studio 2012 C# by using Cplex 12.3 as MILP solver. The data have been collected during several interviews with trucking companies and logistic service operators and refer to an area of about 300 kilometers and a time horizon of one day. The data used to test the proposed schemes regard a real demand of trips related to the seaport basin of the Ligurian ports of Genoa, Savona and La Spezia, and their hinterlands around the cities of Milan and Turin. The information collected are the following: the typology of trips (import, export or inland), origin and destination nodes as well as node time windows, trip due-dates, type of goods transported, operative costs. Delay costs have been estimated on the basis of the fees imposed by terminal operators and by quantifying the annoyance due to the possibility of losing a ship departure or not respecting the original schedule. Tables 3.4 and 3.5 provide the data related to the trips considered in the experimental campaign; in particular, Table 3.4 presents the data related to inland trips, while Table 3.5 refers to import and export trips.

The last columns of Tables 3.4 and 3.5 show the values related to the goods compatibility index. As explained in Section 3.1.3, this index reflects the degree of “dirtiness” of the goods filled in the containers: numbers 1, 2 and 3 mean respectively “very dirty”, “dirty” and “clean”. So, trips can be combined in the same route only if this index decreases in a combination or remains the same (e.g., 2-1-1, 3-2-1 or 3-2-1-1 are admissible combinations).

The unitary delay cost is assumed to be 15 euro/h, while the repositioning distance is a real data provided by the interviewed operators.

Seven sets of trips (i.e. 7; 9; 11; 14; 17; 25; 30) and four scenarios $S1 \div S4$ (Table 3.6) have been considered, which differ for the type of trip, the opening and closing times of nodes and the trip due-date. The following classification has been used:

- $(T - A)$: the majority of trips are of inland type;
- $(T - B)$: the majority of trips are of import/export type;
- $(W - A)$: opening and closing time windows of nodes are less restricted;
- $(W - B)$: opening and closing time windows of nodes are more limiting;
- $(D - A)$: trip due-dates are less restricted;
- $(D - B)$: trip due-dates are more bounded.

More specifically in scenarios $S1$ and $S2$, trip due-dates and node time windows are set large enough to minimize delay costs and to allow the maximum number of trip combinations in a route, whereas in scenarios $S3$ and $S4$, trip due-dates and node time windows are both set to be as strict as possible.

Table 3.4: Data related to inland trips

Trip #	Typology	Distance	Time window	Due-date	Comp. index
		(km)	(hour)	(hour)	
	T-A	T-A	W-A	D-A	
1	imp	160	7 - 12 /15 - 18	15	3
2	inl	41	7 - 13 /15 - 18	18	3
3	exp	178	8 - 13/15 - 18	18	3
4	imp	133	7 - 12/16 - 20	17	2
5	inl	50	8 - 13/15 - 18	15	1
6	inl	64	8 - 13/14 - 18	14	2
7	inl	80	8 - 12/15 - 20	15	1
8	inl	28	8 - 13/15 - 18	18	2
9	inl	70	8 - 13/14 - 18	18	1
10	inl	75	8 - 13/15 - 18	16	2
11	exp	116	8 - 13/15 - 19	18	2
12	inl	74	8 - 13/15 - 18	18	3
13	inl	49	9 - 13/14 - 19	18	2
14	inl	52	8 - 13/15 - 18	20	1
15	inl	38	8 - 13/15 - 18	18	2
16	inl	60	8 - 13/15 - 18	18	2
17	imp	140	8 - 12/15 - 20	18	3
18	inl	37	8 - 12/ 15 - 20	18	1
19	inl	110	8 -13/ 15 - 18	18	2
20	exp	90	7 - 12/16 - 20	18	2
21	imp	40	7 - 12/16 - 20	18	1
22	inl	90	8 - 13/15 - 18	16	2
23	exp	80	9 - 13/14 - 19	20	3
24	exp	167	7 - 12/16 - 20	20	3
25	inl	126	9 - 13/14 - 19	15	2
26	inl	62	8 - 12/15 - 20	18	2
27	exp	144	9 - 13/14 - 19	18	3
28	imp	137	8 - 13/14 - 18	18	1
29	inl	110	8 - 13/15 - 18	16	2
30	exp	120	7 - 12/16 - 20	20	3

The effect of time windows and due-dates is basically different: time windows, being hard constraints, limit the number of trips that can be combined in a route, while due-dates usually affect the cost saving by decreasing it when delay costs occur.

The maximum number of trips has been determined on the basis of the real data available. It is worth underlining that, considering a daily basis and the activity of a single carrier, 30 is a realistic number of trips in a medium-sized port area such as the one of the Italian ports of Genoa, Savona and La Spezia.

Table 3.5: Data related to import and export trips

Trip #	Typology	Distance (km)	Time window (hour)	Due-date (hour)	Comp. index
	T-B	T-B	W-B	D-B	
1	inl	60	8 - 9/16 - 17	13	2
2	inl	50	8 - 9/16 - 17	17	2
3	imp	115	8 - 9/16 - 17	16	1
4	imp	124	8 - 9/16 - 17	16	3
5	exp	167	8 - 9/16 - 17	20	3
6	exp	130	8 - 9/15 - 16	18	1
7	imp	116	8 - 9/16 - 17	13	3
8	imp	120	8 - 9/16 - 17	14	3
9	imp	130	8 - 9/15 - 16	15	2
10	inl	70	8 - 9/15 - 16	14	1
11	inl	45	8 - 9/15 - 16	17	2
12	imp	115	8 - 9/15 - 16	16	3
13	inl	54	8 - 9/15 - 16	12	1
14	inl	54	8 - 10/15 - 16	16	2
15	imp	140	8 - 9/15 - 16	17	1
16	inl	60	8 - 9/15 - 16	14	2
17	inl	56	8 - 9/16 - 17	15	1
18	imp	116	8 - 9/16 - 17	16	3
19	imp	130	8 - 9/15 - 16	17	2
20	inl	58	8 - 9/16 - 17	15	3
21	inl	110	8 - 9/16 - 17	16	2
22	imp	150	8 - 9/15 - 16	12	2
23	inl	56	8 - 9/15 - 16	13	1
24	inl	48	8 - 9/16 - 17	18	2
25	imp	158	8 - 9/15 - 16	17	2
26	inl	60	8 - 9/16 - 17	14	2
27	inl	57	8 - 9/15 - 16	17	1
28	inl	56	8 - 9/15 - 16	15	2
29	imp	130	8 - 9/15 - 16	12	2
30	inl	58	8 - 9/16 - 17	18	2

Table 3.6: Considered scenarios

	W-A	W-B
	D-A	D-B
T-A	<i>S1</i>	<i>S3</i>
T-B	<i>S2</i>	<i>S4</i>

3.5.1 Comparison of optimization schemes

In the following, a comparison between the proposed schemes is performed. Six cases are considered:

- *Case 1 - No trip combinations*: all trips are performed singularly, without any combination;
- *Case 2 - Fixed-2*: trips are combined in two by two (2-trips) combinations;
- *Case 3 - Fixed-3*: trips are combined in three by three (3-trips) combinations;
- *Case 4 - Fixed-4*: trips are combined in four by four (4-trips) combinations;
- *Case 5 - Sequential*: trips are combined in combinations of 4-3-2 trips respectively, determined in a sequential way. In this case, the mathematical model is applied three times, with the proper modifications, respectively for the 4-trips, 3-trips and 2-trips sized combinations;
- *Case 6 - Variable size*: in this case, the mathematical model is applied and variable-sized trip combinations are provided as an outcome of the problem.

Table 3.7 shows the comparison between the situation in which trips are not combined (*Case 1*) and the various combination methods for each considered scenario. The comparison is performed in terms of the percentage of cost saving obtained with the proposed schemes with respect to the total cost C_{tot} required for performing all trips singularly. Note that C_{tot} in scenarios *S1* and *S3* is always lower than the corresponding one for scenarios *S2* and *S4* since inland trips are on average shorter than import/export ones, thus requiring smaller costs.

By observing the obtained results, there is a clear improvement of cost savings in the *case 6 - Variable size* optimization method. This is due to the fact that this scheme is more flexible in the choice of the most proper types of combinations, thus maximizing the cost benefit. For instance, when applying *case 6 - Variable size* to a demand of 9 trips and to scenario *S1*, the types of combinations generated may be “two 4-trip combinations + one single trip” or “three 3-trip combinations”, with a total of three routes in both cases, whereas *Case 2 - Fixed-2* may generate “four 2-trip combinations + one single trip”, i.e., five routes that require higher transportation costs compared to the former case.

Moreover, when increasing the demand of trips to be combined, the difference between the cost savings generated by the *fixed size* methods (especially *Case 2*) and the ones produced by *Case 5* and *Case 6* is higher. This is due to the fact that, when a larger number of trips is considered, *Case 5* and *Case 6* can take into account a bigger number of combinations to find the most profitable ones.

By looking at the different scenarios it can be further observed that when node time windows and trip due-dates are more restrictive as in scenarios *S3* and *S4*, lower cost savings are generated. This can be noted by zooming into a demand consisting of 17

trips for which Fig. 3.7 shows the comparison between the cost saving percentage obtained in case of scenarios *S1* and *S3* (left side of the figure) and the one referred to scenarios *S2* and *S4* (right side of the figure). The cost savings obtained are always bigger in case of Scenarios *S1* and *S2* compared with scenarios *S3* and *S4* due to the impact of more penalizing trip due-dates and time windows in these last scenarios. In fact, when applying scenarios *S2* and *S4*, big size combinations (i.e. 4-trip and 3-trip ones), which are more profitable, are easily infeasible. Then, only small combinations can be exploited and, consequently, the corresponding value of the objective function decreases.

For scenario *S1*, the *variable size*, *fixed-4* and *sequential* approaches obtain the same types of trip combinations and, so, the same objective function value. Instead, for scenarios *S2* and *S3*, the combinations obtained are all different: in the *variable size* scheme 3-trip and 2-trip combinations are allowed and, so, they are chosen in order not to incur in the expensive execution of single trips.

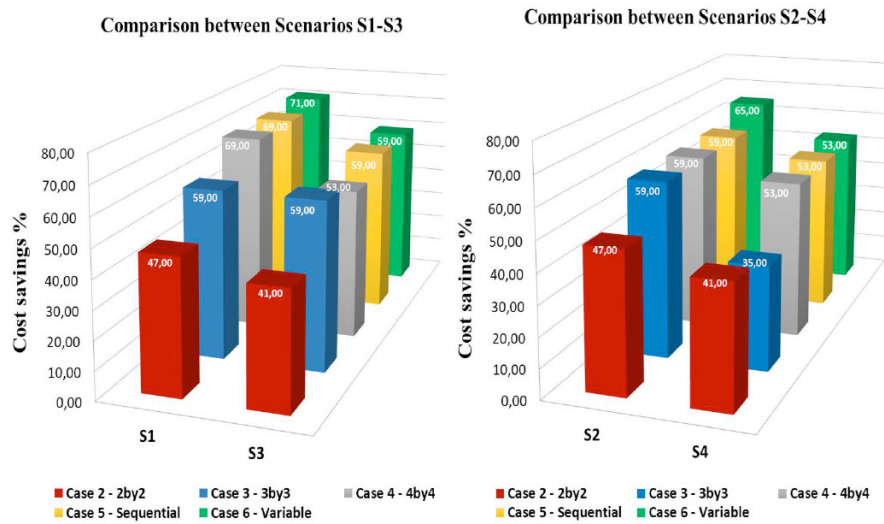


Figure 3.7: Comparisons between scenarios *S1* and *S3*, and scenarios *S2* and *S4* for a number of trips equal to 17 - *Cost savings %*

Another important aspect is represented by the number of routes (i.e. number of combinations of trips) needed to serve the whole transport demand. Figure 3.8 reports the differences in terms of number of routes generated by the proposed optimization schemes and for a different demand. The lowest number of routes is usually generated by *Case 5 - Sequential* and *Case 6 - Variable size* (this also yields a lower number of trucks needed to execute the whole demand of trips).

When node time windows and trip due-dates are more restrictive, such as in scenarios *S3* and *S4*, a higher number of routes is needed compared with *S1* and *S2*, respectively.

Table 3.7: Comparative analysis among optimization schemes for $S1 - S3$, and $S2 - S4$

Trip #	Scen.	Case 1 No combin.	Case 2 Fixed-2	Case 3 Fixed3	Case 4 Fixed-4	Case 5 Sequential	Case 6 Variable size
		C_{tot}	Cost saving %	Cost saving %	Cost saving %	Cost saving %	Cost saving %
7	$S1$	1088	57	57	43	71	71
	$S3$	1088	43	29	43	43	43
	$S2$	1422	57	57	43	71	71
	$S4$	1422	43	54	0	43	43
9	$S1$	1292	44	67	67	67	67
	$S3$	1292	44	67	67	56	67
	$S2$	1866	44	67	67	67	67
	$S4$	1866	44	44	33	56	56
11	$S1$	1532	45	55	55	73	73
	$S3$	1532	45	55	55	55	55
	$S2$	2360	45	55	55	73	73
	$S4$	2360	45	36	27	55	55
14	$S1$	2032	50	57	64	64	71
	$S3$	2032	43	57	64	57	57
	$S2$	3218	50	57	64	57	64
	$S4$	3218	43	29	21	57	57
17	$S1$	2552	47	59	69	69	71
	$S3$	2552	41	59	53	59	59
	$S2$	4036	47	59	59	59	65
	$S4$	4036	41	35	53	53	53
25	$S1$	3766	48	64	72	72	72
	$S3$	3766	40	48	36	36	64
	$S2$	5600	48	64	72	60	64
	$S4$	5600	28	48	48	44	44
30	$S1$	4181	50	67	70	73	73
	$S3$	4181	43	60	67	63	63
	$S2$	6142	50	67	70	67	67
	$S4$	6142	40	60	53	60	60

Obviously, when trips are performed singularly, the number of routes generated is equal to the number of trips.

Again, considering a trip demand of 17 trips, the number of routes classified according to their length (i.e. the number of trips in each route) and obtained as optimal solution of each optimization scheme is shown in Fig. 3.9. It can be noticed that the number of single trips is minimized in the *variable size* case.

Fig. 3.10 presents, instead, the difference of cost saving percentage between the best optimization method, that is *Case 6 - Variable size*, and *Case 1 - no combination* and

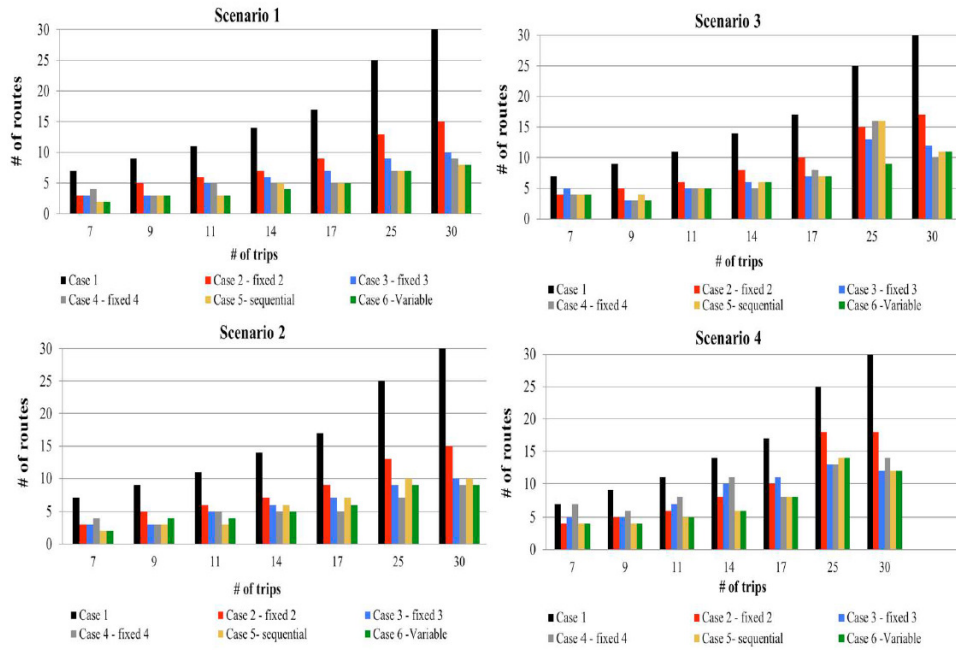


Figure 3.8: Comparison among the number of routes generated in each scheme. Scenarios S1, S3, S2, S4

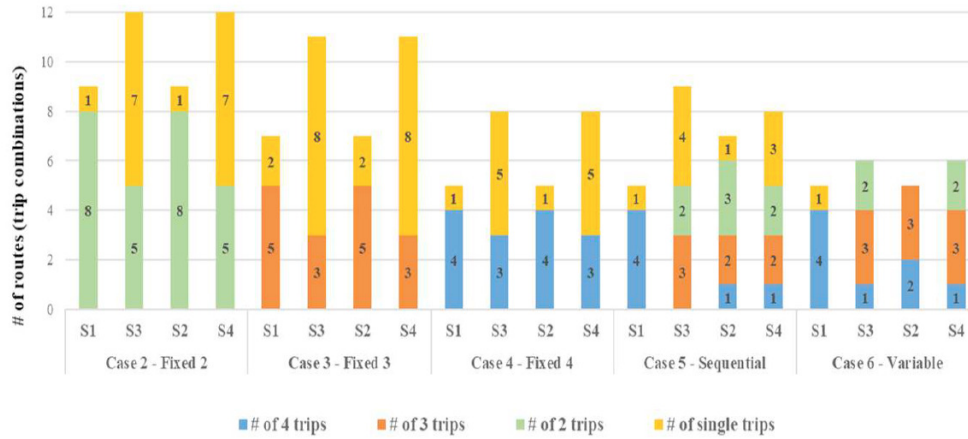


Figure 3.9: Number of routes (trip combinations) with different trip length performed in case of 17 trips for all scenarios and optimization methods

Case 2 - Fixed-2 for all the considered scenarios. Note that *Case 1* and *Case 2* are the ones used by real small-medium sized companies to plan and optimize their trips. The histogram shows that the *variable size* optimization case provides significant benefits

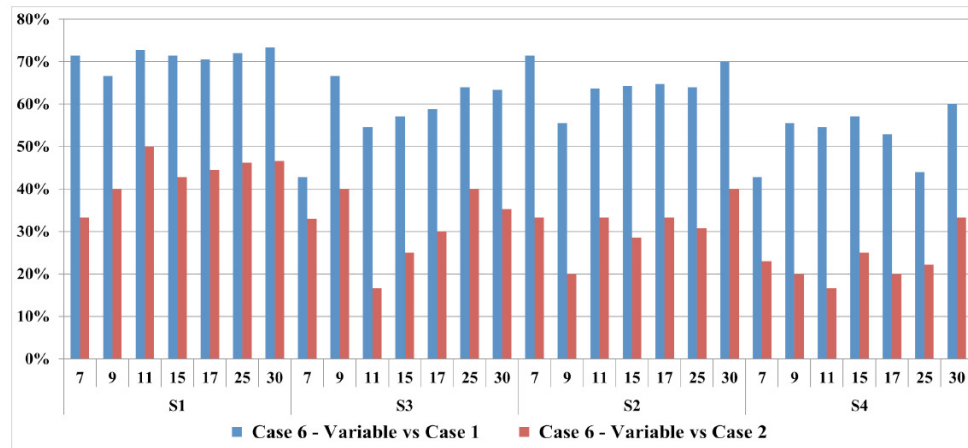


Figure 3.10: Number of routes (trip combinations) with different trip length performed in case of 17 trips with the *variable case* for Scenarios S1, S2 and S3

compared with these two benchmarks.

3.5.2 Comparison with real planning

With the aim of furtherly highlighting the efficiency of the *variable size* optimization method, the solution generated by this approach with the real planning provided by a company located in Northern Italy have been compared . The comparison has been made for both scenario *S1* and *S3* and it considers a real demand of 17 trips to be fulfilled in the hinterland area of the ports of Genoa, Savona and La Spezia, in Northern Italy.

In Tables 3.8(a), 3.8(b) and in Tables 3.9(a), 3.9(b), it is possible to compare the combinations found for scenarios *S1* and *S3* by using the proposed optimization scheme and the real planning, respectively.

Figs.3.11 and 3.12 highlight the planned routes. Red and grey arrows refer to empty and single trips, respectively. It may be observed that in both cases the real planning (right sides of Figs. 3.11 and 3.12) generates a significantly higher number of empty trips with respect to the solutions obtained by the *variable size* optimization approach (left sides of Figs. 3.11 and 3.12).

As pointed out in the previous paragraph, scenario *S1* performs better than scenario *S3* since it is characterized by more convenient trip due-dates and node time windows. It can also be observed that the route *3-6-10-17* (that is performed in both scenarios when applying the *variable size* method) starts in the port of La Spezia and ends in the port of Genoa, without a last repositioning trip. This is possible since, in that case, the shipping company owns empty depots in both ports, allowing to leave the empty container indifferently in one of the two.

Table 3.8: Trips combinations performed as an output of the *Case 6 - Variable* method (8a) and a real planning (8b) for scenario *S1*.

(a) <i>S1</i> -Case 6				(b) <i>S1</i> -Real plan.			
4	3	2	1	4	3	2	1
trips	trips	trips	trip	trips	trips	trips	trip
4-7-13-15			11			16-12	17
1-5-9-14						4-7	
3-6-10-17						1-14	
2-8-12-16						5-9	
						13-15	
						2-8	
						10-6	
						3-11	

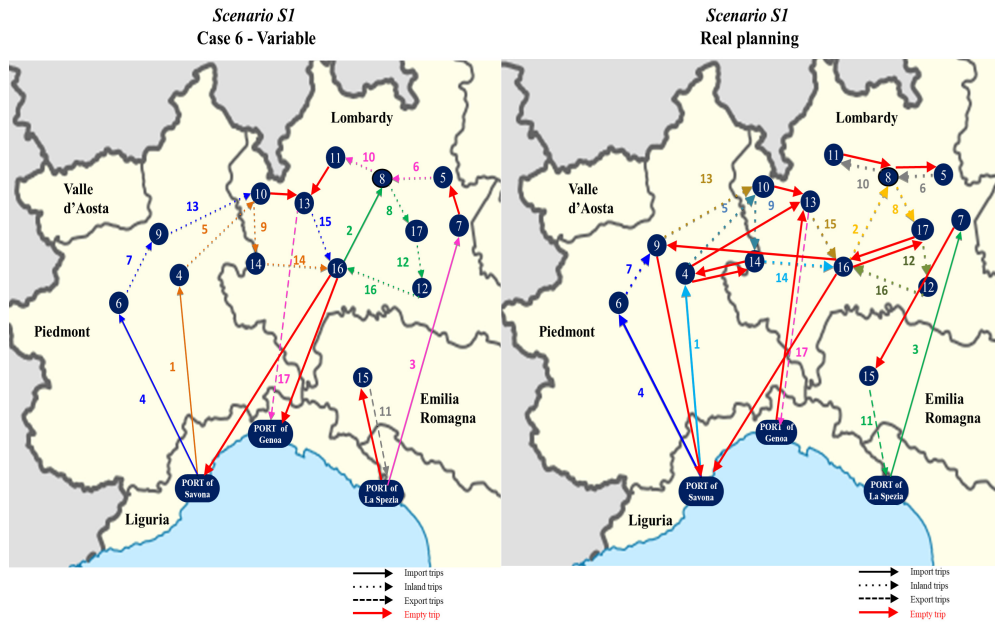


Figure 3.11: Plot of the solutions obtained for scenario *S1* and 17 trips: comparison between *Case 6 - Variable size* and a real planning

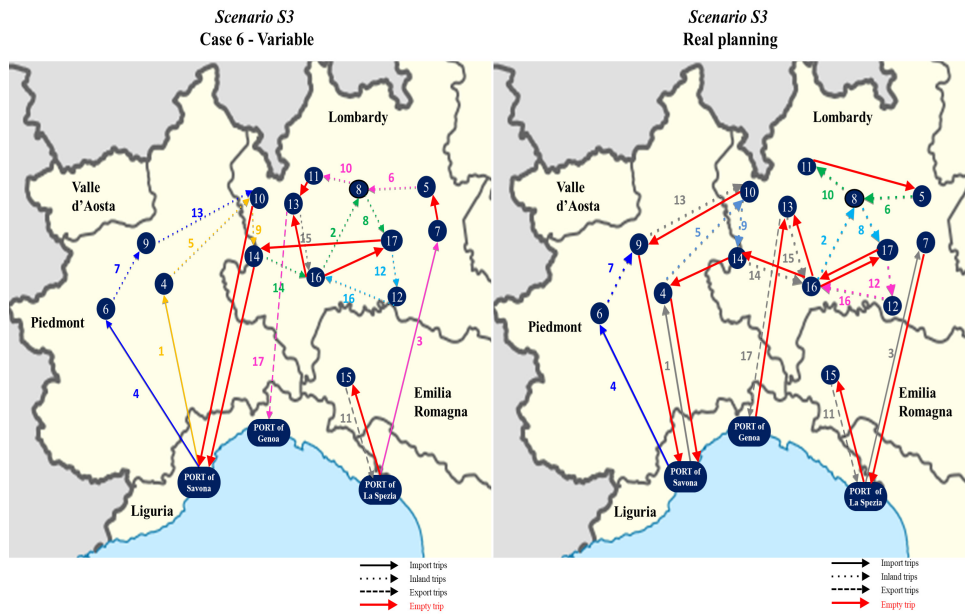


Figure 3.12: Plot of the solutions obtained for scenario *S3* and 17 trips: comparison between *Case 6 - Variable size* and a real planning

Table 3.9: Trips combinations performed as an output of the *Case 6 - Variable* method (8a) and a real planning (8b) for scenario *S3*.

(a) <i>S3</i> -Case 6				(b) <i>S3</i> -Real plan.			
4	3	2	1	4	3	2	1
trips	trips	trips	trip	trips	trips	trips	trip
3-6-10-17	14-2-8	16-12	11			16-12	17
	4-7-13		15			4-7	15
	1-5-9					6-10	3
						5-9	14
						2-8	1
							11
							13

3.5.3 Computational Analysis

A computational analysis has been carried out in order to test the practical applicability of the proposed approach. All the computations have been executed using a laptop with the following features: Intel R core TM i5 CPU M430 2,27 GHz with 4 GB of RAM.

The maximum number of trips that have been considered is 30. As already stated, this number is acceptable considering the average trip demand of a single carrier serving a standard port area on a daily basis.

Table 3.10 provides the results obtained for the different considered approaches. Of course, the number of variables and constraints increases when raising up the number of trips, but also for the biggest instances (i.e. 30 trips) the C-plex solver finds a solution within few minutes of computational time.

The *variable size* approach is characterized by a shorter CPU time and a lower number of variables and constraints compared with the *sequential* scheme, making the former a preferable choice between the two methods. Moreover the computational time required by the *variable size* approach is reasonable for a daily problem, making it suitable for daily planning of carrier operators.

Table 3.10: Computational analysis

		Trip	Case 2	Case 3	Case 4	Case 5	Case 6
		#	Fixed-2	Fixed-3	Fixed-4	Sequential	Variable
CPU time (sec)		7	4.2	2.4	9.6	28	9.0
		9	5.4	5.4	10.2	144	10.8
		11	9.8	17.4	22.8	348	18.9
		17	31.4	33.2	44.3	438	38.9
		25	25.0	71.0	122	623	61.85
		30	62	85.0	329	906	34.7

Chapter 4

Horizontal cooperation among road freight carriers

4.1 Problem Description

The current economic context is facing a growing competitive pressure, a deep environmental concerns and implementation of new business models. Logistic collaboration is emerging as a new opportunity for improving connections, increasing the service level, gaining new market shares, enhancing capacities and reducing negative impacts of the bullwhip effect. Nevertheless, the complexity of the decision making process when more partners are involved, should be taken in consideration. Potential partners are more tempted to participate in collaboration settings if aspects of organization and management of coalitions are well defined, the stability of the relationship is ensured and if they can obtain greater benefits than the ones obtained individually.

Therefore, it becomes crucial to determine how to build and manage collaborations efficiently, as well as how to share benefits equitably to ensure the long-term stability of the collaboration. In particular, it is necessary to determine which entity or entities should lead the relationship, what the specific objectives are to aim for, and which information should be shared to support the collaboration. It is also essential to identify the value of the collaboration as well as how benefits will be shared.

Due to the economic downturn and focus on cost reductions, the transport and logistics industry is evolving from a necessary, though low priority function to an important part of business that can enable companies to attain a competitive edge over their competitors.

As described in [139], because profit margins are shrinking especially in the transport-intensive commodity producing sectors, efficient logistics management can in fact be the decisive factor for a company's success, since competition will take

place on the basis of costs, service and timeliness. Once more the increased operating costs cannot be transferred to the customers, because the sector is fragmented and cannot take a stand against the multinational and powerful customers. This situation determines the vicious circle described in the european study CO3 ([139]), where the low profit margins, strong fragmentation and price competition focused to the lowest price and not to the improved quality, determine a stagnant situation where no time and no monetary resources are spent to develop new skills or proactive initiatives are undertaken to structurally improve the service levels. This induces even thinner profit margins and stronger competition, starting another iteration of the vicious circle.

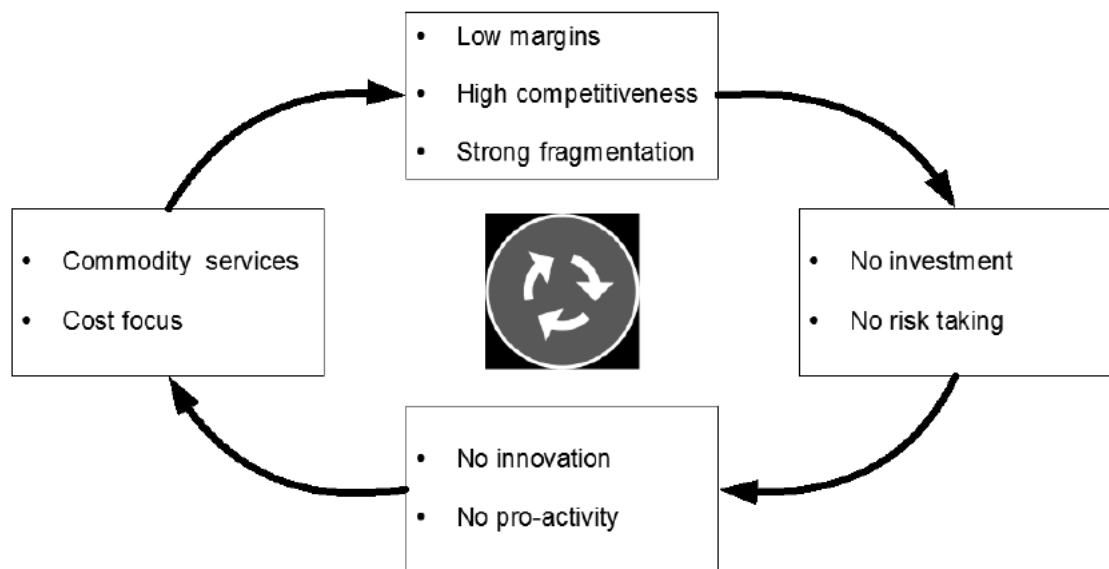


Figure 4.1: The Vicious Circle of Carrier Operators, (Crujssen 2006)

Although not readily available from the Eurostat database, the European Union (2010) in cooperation with Eurostat estimates the value of transport industry to 302 billion euro. However, this industry is heavily fragmented. The 10 biggest European Logistic Service providers do not serve more than 15 % of the total market. A very large share of the trucking companies in the European union even operate five trucks or less, resulting in a highly fragmented industry structure, intense competition and small profit margins. In our country there were trucks and pulling units by April 2017, operated by around 87.371 companies ([146]), which majority is composed by small companies of maximum 5 vehicles and this causes transport inefficiency.

4.1.1 Forms of collaboration

Collaboration can be realized into two directions: vertical and horizontal. In the first case we refer to collaboration across different and heterogeneous levels of the supply chain and the aim is to integrate all the actors in a common agreement. In the case of horizontal collaboration we refer to collaboration among logistics operator at the same level of the supply chain such as trucks operators or shippers. Partners share networks and fleets and could resort to multiple trips combination to service all the transport demand in order to optimize the general demand of transport. In particular, horizontal cooperation is proven to be effective in terms of costs reduction and improving logistics qualities but applications are still rare. The major responsible of this gap is the lack of a proper collaboration model, especially for what concerns costs/gains distribution. This is mostly because participants, though often working towards a common objective, are guided by their own self-interests. Therefore, any proposed mechanism to manage the collaboration's activities should yield collectively and individually desirable solutions. At the highest level, developing a successful collaboration involves two primary tasks: identifying and exploiting synergies between individuals, and allocating the resulting benefits among the collaborators. Benefits depend on interactions between participants and identifying and exploiting synergies often involves solving complex optimization problems and thus may be quite challenging. Benefits could be divided in qualitative and quantitative. We refer to qualitative benefits as social and prestige advantages in consequence of the alliance with other partners, and are never sharable, while quantitative benefits could be sharable or not sharable. When a quantitative benefit is sharable has to be used a proper sharing method to redistribute benefits among participants and it is a crucial moment of the alliance because it must ensure that the benefits gained by each entity make the collaboration acceptable for every one and more attractive than single operability. When a quantitative collaboration is not sharable the distribution of profits could be based on the addition of constraints such as trips deadline to ensure acceptable delivery reductions for each member.

4.1.2 Why to collaborate: collaboration objectives

The objectives of the horizontal collaborations foresee the improvement of efficiency and the reduction of unproductive trips and can be listed as the following:

1. **Cost reduction:** The most frequent objective of horizontal collaboration is cost reduction. Most short-term collaboration initiatives from practice have cost reduction as their primary goal.
2. **Growth Through collaboration:** especially logistics service providers can establish financial growth (increased turnover or profit) or geographically extend their coverage by combining the networks of all partners. Moreover, the bundled forces make it possible to tender on large contracts that are normally only reserved for the bigger players.
3. **Innovation:** Innovative service concepts, the introduction of new systems and technology (e.g., RF tags) and inter-organizational learning can increase the quality of the services offered by cooperating. The new concepts or technology will in many cases be too labor- or capital intensive to be introduced by a single company.
4. **Information and quick response in an economy that is enabled by information flows,** obtaining the most accurate and real time information offers the key to a worldwide competitive advantage. Technological progress in information and communication technology supports cheap and efficient communication between the partners in a network. Besides through best-in-class ICT capabilities, response times can also be shortened by introducing innovative cooperative logistics concepts or by benefiting from partners' distribution or storage networks. For example, courier companies may exchange orders to cut lead times to levels that would be impossible to achieve individually.
5. **Social relevance horizontal collaboration can be an effective way to achieve a higher capacity utilization by exchanging loads and equipment between the geographically dispersed partners.** Load exchanges, central planning, shared distribution centers etc. all increase the efficiency of road transport and are a potential remedy for the increased transport demand. Through horizontal collaboration, the increase in ton-kilometers can be kept under control, even when modal shift is impossible.

In Fig.4.2 Cruijssen et al. (2007a) proposed a list of opportunities of horizontal collaboration divided into three main groups: Costs and productivity, Customer Service and Market position. They have been evaluated with the following options: 1) strongly disagree; 2) disagree; 3) neutral; 4) agree; 5) strongly agree.

To succeed in collaboration means being able to overcome the limitations of the individual approach such as:

1. Shipments and deliveries fragmentation as first cause of inefficient logistics;

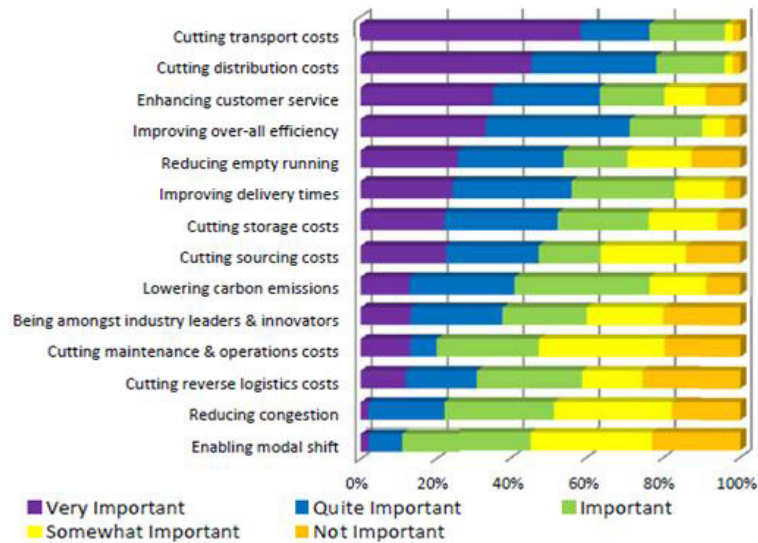


Figure 4.2: Opportunities for horizontal collaboration (Cruijssen 2007)

2. Huge number of empty trips;
3. Conflicts between customers and operators. Collaboration and use of common KPI could help transparency of activities and real time sharing information;
4. Modal and international barriers that may be lacking due to the collaboration between all the logistics stakeholders.

Successful factors of collaboration are presented by:

1. Find ways where all participants can gain;
2. Choose partners for their ability to work together in the long term and not just in the short term;
3. Implementation of cooperation in areas where there is a solid basis to build on the strengths and not to compensate for weaknesses;
4. Manage performance measurement and impacts together to prevent misalignment of goals.

In the present Thesis the issue of horizontal collaboration between road carriers is tackled with the object of improving the coalition profit by using an optimization based scheme that will be explained in Section 5.

4.1.3 How to build logistic collaborations

The way to establish a collaboration framework depends on two main elements: the information sharing and the business interaction, as well as the degree of interaction between partners. For instance, companies that decide to set a simple form of collaboration may exchange only transactional data such as orders, payments, delivery confirmation etc. On the other hand, companies that decide to jointly plan operations should agree on objectives, share strategic information such as customer demand, forecasts and operational capacities and decide on key performance indicators. Interaction between partners must be lead during the whole lifecycle of the collaboration, that Simatupang et al. in [110] describe as four step process:

1. engagement: in this phase the aims are the identification of the strategic needs, of right partners and the set of mutual agreements concerning performance;
2. planning: in this phase are planned resources, tasks and capabilities for future requirements;
3. implementation: members of the coalition perform daily operations to effectively meet the short and long term goals;
4. evaluation process: is set to evaluate and decide whether if the coalition needs any change.

Motivation is another key element of the collaboration success that authors of [110] defined with these three strategies:

1. Reward observable actions that lead to a common goal, rather than reward the attainment of the goal itself;
2. Using performance metrics to evaluate the achievements of individual partners on important objectives of the cooperation;
3. Joint goals are set and the gains that are created are allocated to the partners based on an ex-ante agreed gain-sharing mechanism.

In fig. 4.3 Palmer et al. ([113]) describe how the collaborative framework for the horizontal collaboration should be. This framework has been successively evolved into a business model that includes also the infrastructure used to support the collaboration, the relationship between partners and the financial elements covering costs, services and gain sharing mechanism.

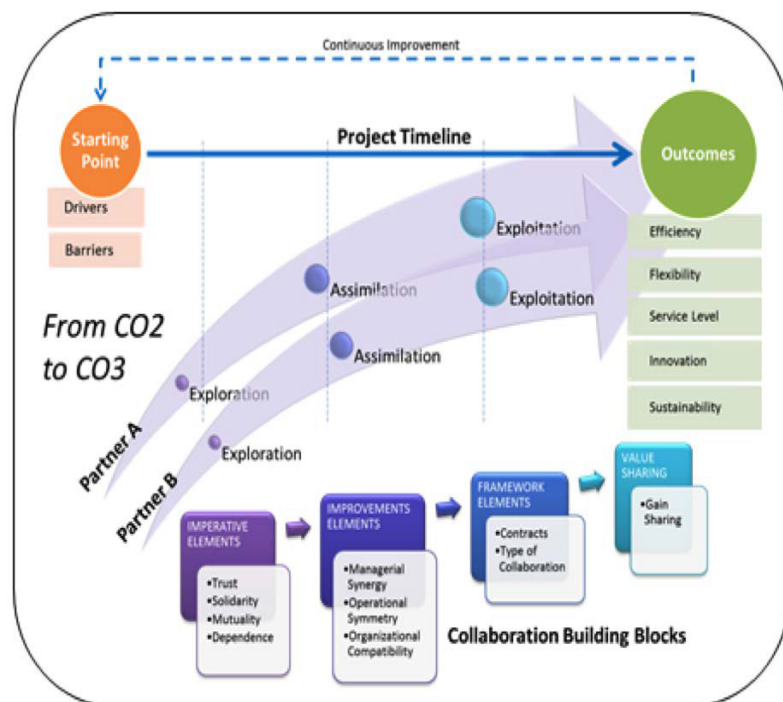


Figure 4.3: Collaborative framework (Palmer 2003)

4.1.4 Choice of the partners

The element that characterizes all the collaboration alliances is the choice of suitable partners. Collaboration is based on trust, information sharing, decision synchronization and incentive alignments. According to the literature, [82] listed the main issues that influence partners' trust.

1. Commitment: the ongoing relationship is worth working on to ensure that it endures indefinitely. Commitment is considered the least factor that can influence partners' behavior and trust ([105]).
2. Capability: is searched during the partners' selection, is defined as competence or work standard, skill, knowledge, and ability required to fulfill a promise, agreement, or obligation ([131]).
3. Information sharing: is as the act of capturing and disseminating timely and relevant information for decision makers to plan and control supply chain operations ([115]). Information sharing must be timeless and of relevant and accurate information.
4. Communication: is the contact and message transmission process in terms of frequency, direction, mode and influence strategy ([135]).
5. Asset specificity: are transaction-specific investments involving physical or human assets that are dedicated to a particular relationship and cannot be redeployed easily ([106]).
6. Resource sharing: the process of leveraging capabilities and assets and investing in capabilities and assets with supply chain partners. Essentially, these concepts drive entities to collaborate, when underlying resources are difficult to redeploy ([135]).
7. Joint knowledge creation: the extent to which supply chain partners develop a better understanding of and response to the market and competitive environment by working together ([135]).
8. Incentive alignment: the process of sharing costs, risks, and benefits among supply chain partners. Saving allocation: partners share benefits of collaboration fairly ([135], [116], [141], [120], [136], [142], [110], [129]).
9. Bargaining power: The ability of a person, group, or organization to exert influence over another party in order to influence the outcome of the negotiation and to achieve a favorable deal ([116]).
10. Opportunism: A particular form of inconsistency of purpose, involving disclosure of incomplete/misleading information, especially calculated efforts to mislead, distort, disguise, confuse, or cause confusion and usage of alliance resources: Fair or unfair usage of alliance resources to create a value outside of the alliance ([132]).

4.1.5 Managing collaboration

The most difficult aspect of the collaboration is its management. With the only term management is taken into account:

- the definition of leadership
- the mechanism of the benefits and costs sharing;
- the determination of who is responsible of what;
- the definition of what can be shared and which information are needed.

The leadership of the alliance depends on serious of factors such as the dimension of the alliance as well as their contribution and organization philosophy. [128] have identified six different forms of leadership currently used in transportation.

1. A supplier/customer/producer leads the collaboration: it aims to minimize its transport costs by finding other customers/producers that can provide a good equilibrium (geographical, volume and time) between supply and demand.
2. A carrier/3PL leads the collaboration: it aims to maximize its profit by a better usage of its carrying capacity.
3. A coalition of suppliers/customers/producers shares the leadership of the collaboration: they aim to minimize their transportation costs.
4. A coalition of carriers/3PLs shares the leadership of the collaboration: they aim to maximize their profit by a better usage of their joint carrying capacity.
5. A coalition of carrier(s)/3PL(s) and supplier(s)/customer(s)/producers(s) shares the leadership of the collaboration: they aim to minimize their transportation costs by using the carrying capacity of the carriers.
6. A 4PL leads the collaboration: it aims to minimize/maximize the cost/profit of its partner.

In the present Thesis the leadership of the alliance is decentralized and shared between the members of the coalition with the aim of reducing transportation costs and increasing individual profit by an optimized distribution of routes and unbalanced trips.

4.1.6 Methods for sharing benefits

In a successful collaboration scheme, the gain sharing mechanism must be effectively designed. It must be fair and understandable by every member of the coalition. In the literature, it can be observed that most of the collaboration rules distribute savings proportionally to a single indicator of either size or contribution to synergy ([139]), a non exhaustive example list could be:

- proportional to the number of customers served
- proportional to the logistic costs before the collaboration
- proportional to the distance travelled for each trip
- proportional to the number of trips
- equal splits

These rules are simple and transparent but if the gain share is only proportional to the number of trips executed without taking into consideration the distance travelled, the carrier who serves an huge quantitate of short distance trips obtains more synergy than one that perform a lower number of long distance trips. Proportional rules may also allocate to a subgroup of participants more costs than the subgroup's individual costs, ([127]), determining the necessity to accurately quantify the marginal contributions of each member of the coalition to the total gain. This issue is addressed by some cooperative game theory rules.

Game theory is considered as a decision aiding tool for collaboration issues. The "game" is intend as a description of the possible strategic interaction that participants (players) can undertake by submitting some certain constraints and interest. Games are distinguished in "cooperative" and "non - cooperative".

The *Cooperative game* takes place when commitments (agreements, promises etc) are fully binding and enforceable. It is applied when potential collaborators can achieve more benefit by collaborating than staying alone. The focus is centered on cooperative behavior by analyzing and simulating the negotiation process within a group of players in establishing a contract of the collaboratively generated revenues allocation or collaboratively avoided costs. In particular, the possible levels of collaboration and the revenues of each possible coalition (a subgroup of the players'consortium) are taken into account so as to allow for a better comparison of each player's role and impact within the group as a whole. In this way, players in a coalition can settle on a compromise allocation in an objectively justifiable way, moderated by a trustee.

Some of the most well known game theoretical gain sharing mechanism are here introduced and will be exploited in section 5.4. *Cooperative Game Theory* addresses both the *Gain Sharing* and *coalition formation*. With "gain" is defined the utility generated in collaboration, and "coalition" represents the group of players that could be the potential collaborators. The coalition formation focuses on which coalitions

should form to maximize the total utility generated by collaboration under stability constraint, while the gain sharing emphasize the fairness of utility allocation, which provoke incentive to stable long term collaboration. The "utility" concept is the focus of both gain sharing mechanisms and coalition formation problems, and could be defined as the amount of benefits achieved thanks to the collaboration. It could be *transferable* or *non transferable* between the players. To the first case refers the Transferable utility games (TU-games) where the sum of all player payoff equals the total utility generated by the collaboration, while in the non transferable utility games (NTU games) the sum of all players payoff is not equal to the total utility of the collaboration. Another distinction between the cooperative game approaches has been individuated by [126] who defined the *Core like* and *Value like* approaches. The former give a set of possible utility allocations for coalition members. These allocations conform to some general properties of feasible solution, thus can be considered as "the set of more feasible propositions". Since that *Core like* approaches only propose a set of solutions, without identifying a specific proposition, they usually serve as stability criterions. The *Value like* approaches, such as Shapley value (SV), try to identify a specific allocation by a set of axioms, usually serve as allocation rules.

The *non cooperative game* takes place if the commitments are not enforceable. In this case players have contradiction on individual objects, such as in the "zero sum game", where the gain (or loss) of a participant is exactly balanced by the loses (or gains) of the other participants. In the present Thesis are not taken into account thus the focus on carrier collaboration based on cooperative alliances.

The sharing of horizontal collaboration benefits could be achieved not only by applying Game Theory allocation methods, but also adopting some optimization schemes, as the one proposed in the present Thesis (5) where the aim of the total coalition profit is foresees, respecting the fairness of cost distribution and the rise of individual profit compared to the individual case. Furthermore the dimension of the carrier alliance is not defined a priori but determined considering the coalition profit.

4.1.7 Limits of collaboration

What about obstacles of logistic collaboration? As in every collaboration mechanism also in the logistic trade there are some difficulties and obstacles that have to be overcome to make reliable the cooperation. Barriers could be:

1. Finding suitable partners and establish detachable and at the same time flexible rules to regulate entry and exit to collaboration based on trust spreading an enterprise culture;
2. Finding a profit sharing mechanism that is commonly accepted by all the members and is able to feel the differences in contribution to the coalition;
3. Finding an appropriate information sharing system to make all the members aware of the trade situation;
4. Finding a legal way to regulate alliance from an organizational point of view and insurance that cover all aspects of the collaboration

4.2 Literature review on carrier cooperation

In the last years, the concept of cooperation among carriers has been gaining an increasing attention in the logistic sector ([140], [112], [114]). As previously described, cooperation can be realized in two different ways: vertical and horizontal cooperation. Vertical cooperation takes place when two or more entities acting at different levels of the logistic network (as instance, suppliers and manufacturers) jointly plan some of their activities. horizontal cooperation, which is addressed in the present Thesis, represents, instead, the collaboration between two or more firms that are active at the same level of the supply chain [125].

The literature on horizontal cooperation in logistics is scarce. Cruijssen et al. [120] provided a review of the existing literature regarding horizontal cooperation. Even if horizontal cooperation is recognized to be a potential way for carriers to increase their positioning in the market of logistic operations, its applications are still rare. This can be due to the fact that participants are mainly guided by own self-interests and they may not yet be aware of the value of cooperation, but, also, a lack of proper collaboration models, especially for what concerns costs and gains distribution, plays a role in the scarcity of cooperation experiences. Therefore, effective methods and procedures to manage collaboration activities could enhance their applications.

Almost all works are focused on the quantification of potential cost savings through collaboration and on the mechanisms to share benefits. Some of those methods are based on simple proportional rules while others on theoretical concepts found in game theory, most of them published in the last ten years. One of the first reviews on basic cost allocation methods is [97], whereas one of the most recent works has been proposed by [143] who classified articles according to five types of problems on collaborative transportation: transportation planning, traveling salesman, vehicle routing, joint distribution and inventory related problems.

The majority of works to solve cost allocation are based on linear optimization programming (LP) and [98] proved that a stable cost allocation, able to distribute the total cost, could be computed from an optimal solution to the dual of the LP. These results are further extended in [99] in which the correspondence of every such cost allocation to an optimal dual solution for a flow game over a simple network is established. [100] and [101] generalized this result and extended it to some LP games that include the games in which this correspondence is known to exist. In [117] and [118] a two steps method to divide the profit gained from the fulfillment of the requests among collaborating carriers is proposed. [111] extended the conventional routing of owned vehicles by introducing subcontracting, simultaneously constructing fulfillment plans with overall lowest costs using the own fleet and subcontractors vehicles.

The above mentioned works refer to decentralized decision schemes; another piece

of work deals with a centralized approach, in which a third party (for instance a logistic provider) takes the responsibility of allocating costs and profits. In [124] the authors studied the network flow from a centralized point of view, in which networks and carrier requests are merged into a big pseudo-carrier. The allocation profit is built on the capacity exchange price, which means that a carrier receives payments for its capacities used by other carriers. In [133] a centralized entity is responsible for minimizing the total costs of carriers. The attractiveness of the centralized cooperation paradigm is justified by the significant increase of capacity utilization and decrease of empty haul trips. Other works study the applicability of cooperative GT properties and propose computational procedures for finding proper allocations. [108] and [109] studied transportation games where buyers and sellers are disjoint sets; [104] considered continuous and discrete network synthesis games. The problem of finding efficient routes, paths and tours able to minimize asset repositioning costs in a collaborative truckload transportation network has been studied by [103], [123]. In these papers some optimization problems with side constraints (such as temporal and driver restrictions) are formulated and some heuristic algorithms are proposed for solving them. [144] studied the optimization of a collaboration scheme among carriers in an arc routing problem with multiple depots. The optimization problem is composed of two phases: in the former the total profit is maximized while in the latter a lower bound on the individual profit of each carrier is identified.

The problem of determining the size of a coalition has, instead, been studied in different sectors apart from logistics: in [107] Axelrod et al. present a theory for predicting how business firms form alliances in the computer science business. They assume that the utility of a firm for joining a particular alliance increases with the size of the alliance and decreases with the presence of rivals in the alliance. Adrian and Press ([102]) defined eight decision costs related to the formation of a coalition in a political system: information, responsibility costs, intergame, division of payoffs, dissonance, inertia costs, time and persuasion costs.

Chapter 5

Multiple trips combination and carriers collaboration: optimization model proposed

In this chapter, the problem of horizontal cooperation between a certain number of road carriers is addressed. The problem has been tackled in this Thesis by defining two phases: an optimization phase devoted to the definition of the best way of performing trips and a second phase in which a suitable way of defining and managing the coalition is addressed. More in detail, once individuated the optimal combinations of trips in section 3.4 for maximizing total cost savings, a second mathematical model, in section 5.1, is defined and applied to properly assign possible combined trips to carriers and, finally, in a third step the most adequate coalition in terms of number of participants is chosen with the aim of maximizing the profit when introducing costs related to the management of the coalition.

In section 5.4 the same problem of profit maximization of carriers' alliances is solved applying Game Theory Methods.

The results obtained in both sections are similar but not coincident, underling the fairness of the allocation models proposed and the fact that in all cases collaboration brings to carriers higher profits than the stand alone situation.

5.1 The optimization phase

Several road transportation carriers are supposed to form a coalition in which they share trips to be served in a common area. Trips belonging to different carriers of the coalition are optimally combined and assigned to the carriers with the final goal of maximizing the total coalition profit. Moreover, the coalition profit is improved by determining the best coalition size, taking into account management coalition costs. The fact of performing trips in combinations instead of singularly, besides optimizing carrier profits, allows to decrease negative externalities such as pollution and congestion, thanks to the reduction of empty trips on road networks.

In the considered framework, trips are characterized by an origin, a destination, a duration (proportional to the distance to be covered) and a due date to be respected.

As regards carriers, a unitary management cost, which reflects the organizational structure of the company, its fixed costs and other factors, is defined together with a unitary income for realizing trips. According to such terms, trips combinations are assigned to carriers. Moreover, a fixed management cost is associated with each coalition size. This cost is assumed to be linearly proportional to the coalition size, assuming that it is more onerous to manage a bigger rather than a smaller coalition.

To sum up, the proposed optimization scheme is composed of the following three phases. (Fig. 5.1).

- *Phase 1:* trips are optimally combined with the goal of maximizing the total cost savings for performing them. The result of this first optimization problem is a certain number of trip combinations having different lengths and maybe some single trips (i.e. the ones which remain uncombined). Note that in this first phase the property of trips is neglected. Results of this phase are presented in section 3.5.
- *Phase 2:* the combined trips obtained as output from the previous phase are assigned to carriers with the goal of maximizing the coalition profit. In this step the size of the carrier coalition is fixed.
- *Phase 3:* in order to define the best carrier coalition size, the optimization problem of phase 2 is performed for different coalition dimensions. Finally, the coalition size that maximizes the total carriers' profit is chosen.

Once solved Problem 3.4.1, the best trip combinations are determined and gathered in set \bar{C} . In the second phase of the proposed optimization scheme, a second mathematical problem is applied in order to assign combined trips to carriers. Note that single trips are not considered in this second optimization phase because they are assumed to be executed by the carrier they belong to. Before presenting this second mathematical formulation, let us introduce the following additional notation:

- \mathcal{R} is the set of carriers;

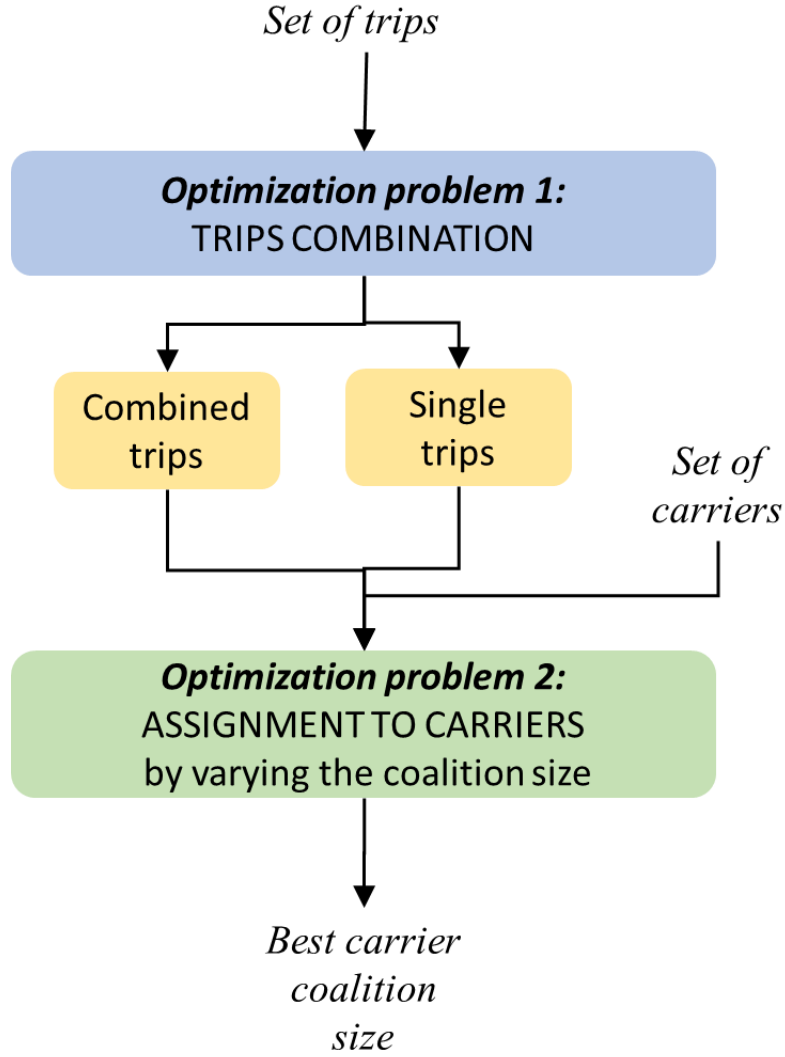


Figure 5.1: Optimization Scheme proposed

- $c^r, r \in \mathcal{R}$, is the unitary cost of carrier r for performing its trips. It is expressed in *euro/km*;
- $e^r, r \in \mathcal{R}$, is the unitary earning of carrier r for performing trips. It is expressed in *euro/km*;
- $\mathcal{T}^r \subset \mathcal{T}, r \in \mathcal{R}$, is the set of trips initially belonging to carrier r ;
- $n^r, r \in \mathcal{R}$, is the number of trucks available for carrier r to execute trip combinations. It is different for each scenario considered;
- $D_c, c \in \overline{\mathcal{C}}$, is a parameter representing the eventual delay cost to be sustained

when executing combination c ; It is defined as $D_c = c_d \sum_{i=1}^{l(c)} \max(f_{v_i(c)} - h_{v_i(c)}, 0)$;

- $S_c^r, r \in \mathcal{R}, c \in \bar{\mathcal{C}}$, is the profit of carrier r for executing trip combination c ;
- $S^r, r \in \mathcal{R}$, is the total profit for carrier r for performing trip combinations;
- $S_0^r, r \in \mathcal{R}, c \in \bar{\mathcal{C}}$, is the initial profit of carrier r for executing trips $t \in \mathcal{T}^r$ that initially belong to him;
- $G(\bar{U}), u \in \bar{U}$ is defined as the total gains of collaboration;
- $u \in \bar{U}$ are all the possible combinations of carrier alliances;
- γ is a parameter that takes into account the need of repositioning the empty container at the end of the service when performing single trips. Note that in some cases, the empty container is asked to be brought back to the origin node; in this case the value of γ is 2.

The initial profit of each carrier is computed as

$$S_0^r = \sum_{t \in \mathcal{T}^r} (e^r - \gamma c^r) d_t \quad r \in \mathcal{R} \quad (5.1)$$

The decision variables of the second problem are represented by $y_c^r, c \in \bar{\mathcal{C}}, r \in \mathcal{R}$, that are binary variables assuming value equal to 1 if trip combination c is executed by carrier r , 0 otherwise.

The second problem formulation follows.

Problem 2. Find the optimal values of variables $y_c^r, c \in \bar{\mathcal{C}}, r \in \mathcal{R}$, in order to:

$$\max \sum_{u \in \bar{U}} G(\bar{U}) \quad (5.2)$$

where: $G(\bar{U}) = \sum_{r \in \mathcal{R}} (S^r - S_0^r)$

subject to:

$$S_c^r = y_c^r \left((e^r - c^r) \sum_{i=1}^{l(c)} d_{v_i(c)} - c^r \sum_{i=1}^{l(c)-1} \epsilon_{v_i(c), v_{i+1}(c)} - D_c \right) \quad c \in \bar{\mathcal{C}}, r \in \mathcal{R} \quad (5.3)$$

$$S^r = \sum_{c \in \bar{\mathcal{C}}} S_c^r \quad r \in \mathcal{R} \quad (5.4)$$

$$\sum_{r \in \mathcal{R}} y_c^r = 1 \quad c \in \bar{\mathcal{C}} \quad (5.5)$$

$$\sum_{c \in \bar{\mathcal{C}}} y_c^r \leq n^r \quad r \in \mathcal{R} \quad (5.6)$$

$$y_c^r \in (0, 1) \quad c \in \bar{\mathcal{C}}, \quad r \in \mathcal{R} \quad (5.7)$$

□

The resulting problem is an Integer Linear Programming (ILP) problem in which the objective function (5.2) minimizes the sum of the transport costs for performing trip combinations plus a term reflecting the difference between the initial (S_0^r) and final (S^r) profit of each carrier. This last term has been added in order to penalize solutions in which the final profit of one or more carriers is lower than the corresponding initial profit. Constraints (5.3) and (5.4) define the initial and final profit of each carrier. Constraints (5.5) ensure that each trip combination c is executed by only one carrier r , while constraints (5.6) ensure that the maximum number of trips combination c that each carrier can perform is not bigger than the maximum number of truck available by the carrier. Finally, constraints (5.7) define the nature of the decision variables of the problem.

5.2 Determination of the coalition size

By optimally solving Problem 3.4.1 and Problem 5.1 it is possible to determine the best trip combinations and, consequently, the highest total profit of the carriers participating in a coalition. It is, then, possible to investigate what happens by considering different coalitions of carriers and, specifically, coalitions in which the number of participants changes. When dealing with such an issue, it is necessary to consider that the larger is the number of participants to a coalition, the higher are the costs needed to manage the coalition.

By defining a set of coalitions \mathcal{A} , it is possible to associate with each element a of the set, the optimal profit \bar{S}_a° obtained by solving Problem 5.1 and a cost $\bar{C}_a = c_a \rho_a$ related to the cost for managing the coalition. This cost linearly depends on the number of participants to the coalition, ρ_a , $a \in \mathcal{A}$, and by a unitary cost for the coalition management c_a .

Therefore, in this third phase, Problem 5.1 is solved several times by considering different coalition sizes, so to determine the best coalition a° that further maximizes the total coalition profit. This optimal coalition can be found by applying the following formula:

$$\operatorname{argmax}_{a \in \mathcal{A}} (\bar{S}_a^\circ - \bar{C}_a) \quad (5.8)$$

Of course, once determined the best coalition, it is straightforward to define the best size for a coalition to face the proposed problem. In the next section an experimental analysis based on a real case study is presented.

5.3 Experimental Results

Once individuated the best trips combinations by applying model presented in section 3.4.1, the second model, described in 5.1, has been applied introducing truck carrier operators to determine the best assignment to carriers. Various instances related to different numbers of trips T have been tested. For example, results obtained in the instances $T = 7$, $T = 17$, $T = 25$, $T = 30$, are presented. The set of carriers includes 5 carriers, that is, $\mathcal{R} = \{A, B, C, D, E\}$. Each one of these instances has been tested in the four scenarios $S1 \div S4$ (Table 3.6) described in 3.5.

Table 5.1 presents an extraction of data related to the trips in the second instance ($T = 17$) from Table 3.4 in which the ID number, the origin, the destination, the distance to be covered, the due-date to be respected and the carrier who originally owns the trip before the collaboration process, are reported for each trip.

Table 5.1: Data related to trips in the second instance ($T = 17$)

Trip #	Typology	Distance (km)	Time window (hour)	Due-date (hour)	Carrier owner
	T-A	T-A	W-A	D-A	
1	imp	160	7 - 12 / 15 - 18	15	A
2	inl	41	7 - 13 / 15 - 18	18	B
3	exp	178	8 - 13 / 15 - 18	18	C
4	imp	133	7 - 12 / 16 - 20	17	A
5	inl	50	8 - 13 / 15 - 18	15	C
6	inl	64	8 - 13 / 14 - 18	14	D
7	inl	80	8 - 12 / 15 - 20	15	C
8	inl	28	8 - 13 / 15 - 18	18	E
9	inl	70	8 - 13 / 14 - 18	18	C
10	inl	75	8 - 13 / 15 - 18	16	E
11	exp	116	8 - 13 / 15 - 19	18	B
12	inl	74	8 - 13 / 15 - 18	18	D
13	inl	49	9 - 13 / 14 - 19	18	C
14	inl	52	8 - 13 / 15 - 18	20	D
15	inl	38	8 - 13 / 15 - 18	18	A
16	inl	60	8 - 13 / 15 - 18	18	E
17	imp	140	8 - 12 / 15 - 20	18	A

Results obtained by applying Problem 5.1 are summarized in Table 5.2. For all the carriers the unitary earning e^r has been set equal to 1, while the unitary costs of transport c^r have been set equal to 0.8, 0.9, 0.9, 0.8, 0.9 for carriers A, B, C, D, E , respectively.

Comparing individual carriers profits in the different scenarios is confirmed the tendency already described in 3.5, where, when node time windows and trip due

Table 5.2: Trips assignment to carriers ($S1$)

r	S_0^r	S_c^r			%of sav.			n^r	
		$\rho_a = 3$	$\rho_a = 4$	$\rho_a = 5$	$\rho_a = 3$	$\rho_a = 4$	$\rho_a = 5$		
1	A	70	89	76	72	21%	8%	3%	4
	B	68	91	78	71	25%	13%	4%	4
	C	63	95	66	64	34%	5%	2%	3
	D	53	-	55	53	-	4%	0%	3
	E	46	-	-	47	-	-	2%	3
	S_{tot}	300	275	275	307	27%	8%	8%	
2	A	150	175	171	170	14%	12%	12%	5
	B	145	181	165	151	20%	12%	4%	5
	C	145	194	163	149	25%	11%	3%	4
	D	126	-	148	140	-	15%	10%	3
	E	118	-	-	121	-	-	2%	3
	S_{tot}	684	550	647	731	20%	13%	6%	
3	A	219	258	294	316	15%	26%	31%	6
	B	228	285	325	336	20%	30%	32%	5
	C	204	244	258	305	16%	21%	33%	5
	D	217	-	236	230	-	8%	6%	4
	E	239	-	-	241	-	-	1%	3
	S_{tot}	1107	787	1113	1428	17%	22%	22%	
4	A	487	576	608	649	15%	20%	25%	6
	B	498	584	625	658	15%	20%	24%	5
	C	479	501	629	624	4%	24%	23%	5
	D	490	-	585	593	-	16%	17%	4
	E	498	-	-	622	-	-	20%	4
	S_{tot}	2452	1661	2447	3146	12%	20%	22%	

to dates are more restrictive ($S3$ and $S4$) also individual lower profits are generated. Figure 5.2 shows this scenario comparison in the case of $\rho_a = 3$.

In Table 5.2 is possible to analyze the results obtained growing the dimension of carrier alliances. Results are reported for the *scenario 1* case, in terms of initial profit of each carrier S_0^r and final profit obtained by applying collaboration S^r , and the relative % of profit for the 5 instances considering coalitions of carriers with growing dimensions (with $\rho_a = 3$, $\rho_a = 4$ and $\rho_a = 5$).

It is possible to see that in case of small trip sets, as it is the first instances, that is composed of only 7 trips, the highest savings are obtained by applying a small coalition ($\rho_a = 3$). For instances 2, that has 17 trips, the difference in terms of profits for alliances of 3 and 4 carriers is less big that the one for the first instance.



Figure 5.2: Comparison between scenarios $S1$ and $S3$, and scenarios $S2$ and $S3$ for the set of $T = 7, 17, 25, 30$ trips, with the growing size of collaboration alliance $\rho_a = 3, 4, 5$

Nevertheless profits in the case with $\rho_a = 5$ are still lower than the one obtained for $\rho_a = 3, 4$. Instead for instances 3, that has 25 trips, results show that a carrier alliance of 4 members is more profitable. For instances 4 the highest profits are obtained by applying a coalition with $\rho_a = 5$. This trend is in line with the fact that the higher is the number of trips to be served, the higher is the need to distribute them between more carriers in order to produce a profitable service both for each carrier and for the whole set. It is also visible in fig.5.3, where the total coalition profit increase with the dimension of the coalition: small trip sets (i.e. 7 trips) obtain higher profit for small

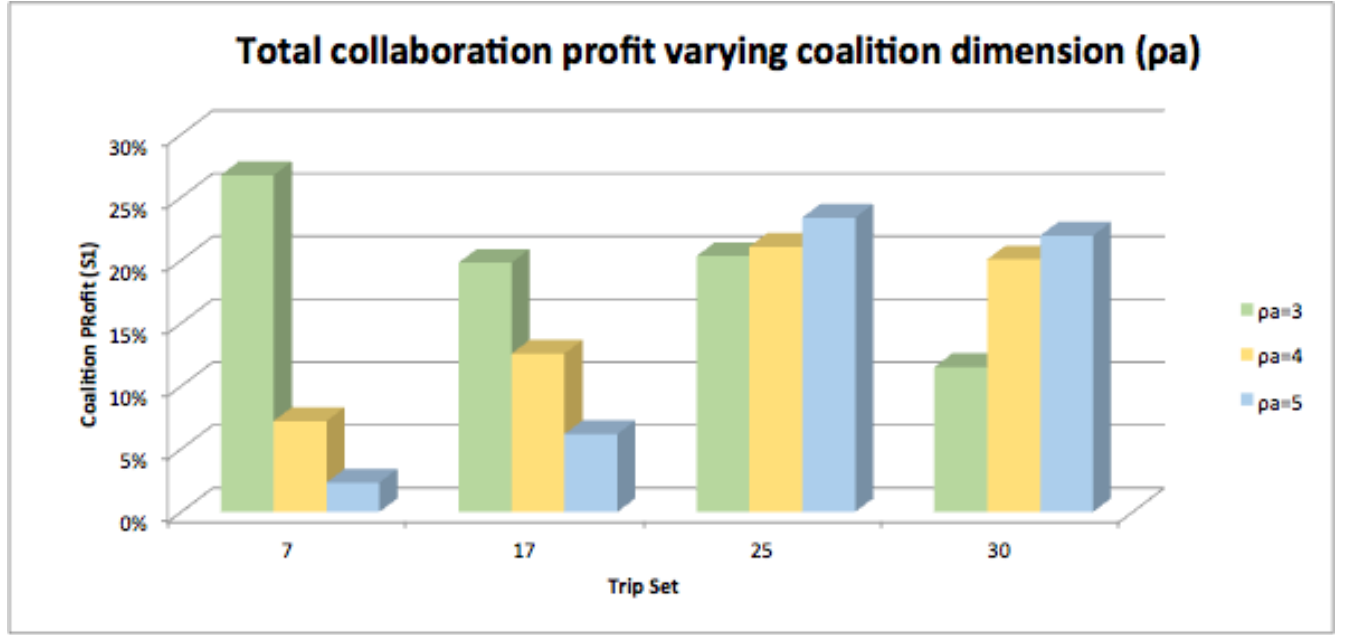


Figure 5.3: Total collaboration profit for the set of $T = 7, 17, 25, 30$ trips, with the growing size of collaboration alliance $\rho_a = 3, 4, 5$

carrier alliances ($\rho_a = 3$), instead big trip sets (i.e. 30 trips) register higher profits with big carrier alliances ($\rho_a = 5$)

To justify this tendency and to properly size the coalition, Problem 5.1 has been applied for each coalition type ($\rho_a = 3, \rho_a = 4, \rho_a = 5$) by varying the value of the management cost of the coalition. This has been done for all the five scenarios considered.

In Table 5.3 the results for the different scenarios are summarized. Reading values in rows, it is possible to see that, keeping the same number of trips but increasing the value of the unitary costs, the dimension of the carrier alliance decreases.

Instead, reading values in columns, it comes out that keeping the same value of the unitary costs and increasing the number of trips considered, the dimension of the carrier alliance increases. This tendency is straightforward since the bigger is the set of trips to be served, the higher is the number of carriers that form the best coalition. Of course this is due to the structure of the above determined profits and that the cost for managing the coalition is chosen as a linear cost proportionally increasing with the coalition size.

As regards the computational load of the proposed optimization scheme, the computational times are lower than 100 seconds for each scenario analyzed.

Table 5.3: Dimension of carrier alliances in function of T and c_a

T	c_a			
	10	20	30	50
4	3	3	3	3
17	4	3	3	3
32	4	4	4	4
61	5	5	4	4
100	5	5	5	5

5.4 Application of Game Theory Methods for profit allocation

In section 5.1 the best trips combination identified in 3.4 have been allocated to carriers, maximizing their profits, applying the ad hoc method proposed by the present Thesis. To complete the analysis, the same problem has been solved applying GT methods in order to validate results obtained.

5.4.1 Game theory glossary

Before presenting the results obtained can be useful report a brief glossary of the Game Theory.

A cooperative game is an ordered pair $\langle R; \phi \rangle$ where $R = \{1, 2, \dots, r\}$ is the set of players and $\phi : U \rightarrow \mathbb{R}$ is a function that assigns to each coalition $u \in U = 2^N$ a real number and such that $\phi(0) = 0$. ϕ is said "characteristic function" of the game, and $\phi(u)$ is said value of the coalition $u \in U$. Often $\phi(u)$ is called "saved cost" for the coalition u and traditionally it is computed as the difference between the cost corresponding to the situation where all the members of s work alone and the cost related to the situation where all members of s work together. In our approach, it is calculated as the difference between the profit of the coalition s obtainable thanks to the collaboration and the profit of each member of s working alone, that is,

$$\phi(u) = G(u) - \sum_{r \in s} p(r) \quad \forall u \in U \quad (5.9)$$

Moreover, a vector $\xi \in \mathbb{R}^n$ is said imputation if:

- ξ is individual rational (IR) i.e.:

$$\xi_r \geq \phi(r) \quad \forall r \in R \quad (5.10)$$

- ξ is efficient (EFF) i.e.:

$$\phi(R) \sum_{r \in R} \xi_r = \phi(R) \quad (5.11)$$

Equation (5.10) states that the profit of the grand coalition R is split among its members according to the imputation ξ . The second equation (5.11) states that there is no subset u of players such that, should they form a coalition separately from the rest, they would perceive less total profit than the total profit allocated to them by ξ .

Some definitions follow:

Definition 1 (super additive). A game $G = \langle R; \phi \rangle$ is super-additive if the value function ϕ satisfies equation (5.12):

$$\phi(U) + \phi(H) \leq \phi(U + H) \quad (5.12)$$

in a super-additive game the value of the union of two distinct coalitions is great at least as the sum of the sub-coalitions taken separately. Therefore in a super-additive game it is not convenient to break a coalition in parts.

Definition 2 (sub additive). A game $G = \langle R; \phi \rangle$ is sub-additive if $G = \langle R; \phi \rangle$ is super-additive.

Definition 3 (additive). A game $G = \langle R; \phi \rangle$ is additive if the value function ϕ satisfies equation (5.13):

$$\phi(U) + \phi(H) = \phi(U \cup H), U \cap H = \emptyset \quad (5.13)$$

Definition 4 (Convex). A game $G = \langle R; \phi \rangle$ is convex if the value function ϕ is super modular.

$$\phi(U) + \phi(H) \leq \phi(U \cap H) + \phi(U \cup H), \quad \forall U, H \subseteq N \quad (5.14)$$

Definition 5 (Super modular). A game $G = \langle R; \phi \rangle$ is super modular if the value function ϕ is equivalent to:

$$\phi(U \cup i) - \phi(U) \leq \phi(H \cup i) - \phi(H), \quad \forall U \subseteq H \subseteq N, i \in N \quad (5.15)$$

That means the incentives for joining a coalition increase as the coalition grows.

In this thesis some of the main cooperative GT solution concepts are applied, they are, in particular, Core, Nucleolus, Shapley Value, and methods based on marginal or separable and non separable costs. In the standard applications of such methods the distribution of costs is considered, in this thesis instead the distribution of profits is analyzed. In the following the main concepts adopted are defined.

- **Core.** The set C of stable imputations is called "Core" and defined as:

$$C = \left\{ (\xi_1, \dots, \xi_n) : \sum_{r \in R} \xi_r = \phi(R) \right. \\ \left. \text{and } \sum_{r \in s} \xi_r \geq \phi(s), \quad \forall s \in S \right\} \quad (5.16)$$

The Core is the set of all allocations that share out the cost savings in the grand coalition and make every coalition and individual get more than they can achieve by deviating from the grand coalition.

Nevertheless the Core of some games may be empty, as proved by Shapley in 1971. The Core of a game is non-empty only if the coalition formed is the optimal one. "Optimal" means this coalition can generate highest global cost savings. In the sense of the coalition Core stability, the optimal is the most stable.

Even if the coalition Core is empty, in considering that the optimal coalition can achieve the highest global cost saving, which leaves more leeway for the side payment aiming at a global acceptable solution, it is more stable than other coalitions.

- **Nucleolus** is a measure of the inequity of an imputation ξ for a coalition s and is defined in form of excess:

$$e(\xi, s) = \phi(u) - \sum_{r \in s} \xi_r \quad (5.17)$$

Equation (5.17) measures the quantity (i.e. the size of inequity) of distance from its potential $\phi(u)$ for the allocation ξ in coalition s . Since the Core is defined as the set of imputations such that $\sum_{r \in s} \xi_r \geq \phi(u)$ for all coalitions s , it results that an imputation ξ is in the Core if, and only if, all its excesses are negative or zero.

- **The Shapley Value** $\psi(\phi)$ of the game $\langle R; \phi \rangle$ is defined as a function that assigns to each possible characteristic function of a r -person game ϕ , a r -tuple, $\psi(\phi) = (\psi_1(\phi), \psi_2(\phi), \dots, \psi_r(\phi))$ of real numbers. Here $\psi(\phi)$ represents the worth or value of player r in the game with the characteristic function ϕ .

$$\Psi(\phi) = \frac{1}{r!} \sum_{\sigma \in \Pi(R)} m_{\sigma(r)}^{\sigma}(\phi) \quad (5.18)$$

where $\Pi(R)$ denotes the set of permutations of N and the marginal vectors $m^{\sigma}(\phi)$ correspond to a situation in which players enter in a room one-by-one in the order $(\sigma(1), \sigma(2), \dots, \sigma(n))$ and where to each player it is assigned the marginal contribution that he gets when he enters.

$P_{\sigma}(r)$ is the set of predecessors of r in σ .

$$m_{\sigma(r)}^{\sigma}(\phi) = \Psi(P_{\sigma}(\sigma(r)) \cup \{\sigma(r)\}) - \Psi(P_{\sigma}(\sigma(r))) \quad (5.19)$$

The axioms of fairness are placed on the function $\Psi(\phi)$:

- 1 Efficiency (5.11).
- 2 Symmetry. If r and j are such that $\phi(s \cup r) = \phi(s \cup j)$ for every coalition s not containing r and j , then $\Psi_r(\phi) = \Psi_j(\phi)$.
- 3 Dummy Axiom. If r is such that $\phi(u) = \phi(u \cup r)$ for every coalition u not containing r , then $\Psi_r(\phi) = 0$.
- 4 Additivity. If u and v are characteristic functions, then $\Psi_{(u+v)} = \Psi_u + \Psi_v$.

- **Method based on marginal or separable and non separable savings.** Given a game, the marginal saving of player r is called “separable saving” and defined as

$$m_r = \phi(R) - \phi(R - r) \quad (5.20)$$

If the saving sum is lower than the total saving game, the difference between the two values is called “non separable saving”:

$$\Gamma(N) = \phi(R) - \sum_{r \in R} m_r \quad (5.21)$$

There are different methods to allocate this non separable saving $\Gamma(R)$:

- 1 *Equal Profit Allocation (EPA)* This method equally allocates the profits among all the members of the coalition:

$$\xi_r = m_r + \Gamma(R) \frac{1}{r} \quad (5.22)$$

- 2 *Alternative Cost Saving (ACS)* Non separable saving is allocated proportionally to the saving obtained by each member of the coalition having gained own separable profit instead of the individual profit. So it comes:

$$sav_r = \phi_r - m_r \quad (5.23)$$

and then,

$$\xi_r = m_r + \Gamma(R) \frac{sav_r}{\sum_{r \in R} sav_r} \quad (5.24)$$

- 3 *Profit Gap (PGA)* This method allocates the profit proportionally to the best maximum contribution that each player is willing to give for being part of a coalition. So the non separable profit of a coalition s is defined as:

$$\Gamma(s) = \phi(u) - \sum_{r \in s} m_r \quad (5.25)$$

Player r is willing to pay at most the minimum non separable profit of the coalition of which he could be member. Imposing, $g_r = \min\{g(s) | r \in s\}$, ξ_r is computed as follows:

$$\xi_r = m_r + \Gamma(N) \frac{g_r}{\sum_{r \in R} g_r} \quad (5.26)$$

The methods described above are implemented and compared in the following section with reference to a specific example. Specifically, in the present thesis, the above described profit allocation methods have been applied in order to highlight quantified and easily understandable value of profits for carriers. These results show the potential of collaboration and incentive companies to form coalitions.

5.5 Experimental Results

The models described in 3.4 and in 5.1 have been implemented and solved considering different experimental factors to represent a variety of different problem conditions:

- the number of carriers that can collaborate, forming collations of 2,3,4.. carriers;
- the number of trips to be performed (i.e 7,9,11..);
- the original property of trips;

At first, the optimization problem 3.4 has been solved to identify the best trip combinations for different settings u , and the corresponding profit $G(u)$ and value functions $\phi(u)$ have been computed. Then, for each instance tested, the related profit allocations have been calculated by using the methods described in the previous section.

Table 5.4: Profit and Value function obtained from collaboration of 3 carriers

Carr.	Value	7 trips	17 trips	25 trips	30 trips
A	$G(u)$	70	150	219	487
	$\phi(u)$	0	0	0	0
B	$G(u)$	68	145	228	498
	$\phi(u)$	0	0	0	0
C	$G(u)$	63	145	204	479
	$\phi(u)$	0	0	0	0
AB	$G(u)$	167	325	495	1360
	$\phi(u)$	29	30	48	375
AC	$G(u)$	170	319	480	1345
	$\phi(u)$	37	45	57	379
BC	$G(u)$	175	296	475	1309
	$\phi(u)$	44	27	43	332
ABC	$G(u)$	475	978	1489	3005
	$\phi(u)$	274	559	838	1541

For instance, in Table 5.4 the total profit $G(u)$ and the value of each collaboration setting $\phi(u)$ are provided for four scenarios that differ for the total number of trips considered (i.e. 7, 17, 25 and 30) in the case of $\rho = 3$. In Fig. 5.4 is visible how the value of each collaboration setting $\phi(u)$ increase with the dimension of trip set and of the carrier alliance.

The computational time necessary to solve the optimization problems related to the three scenarios of ρ_a is very small and is always lower than 0.05 seconds , 0.08

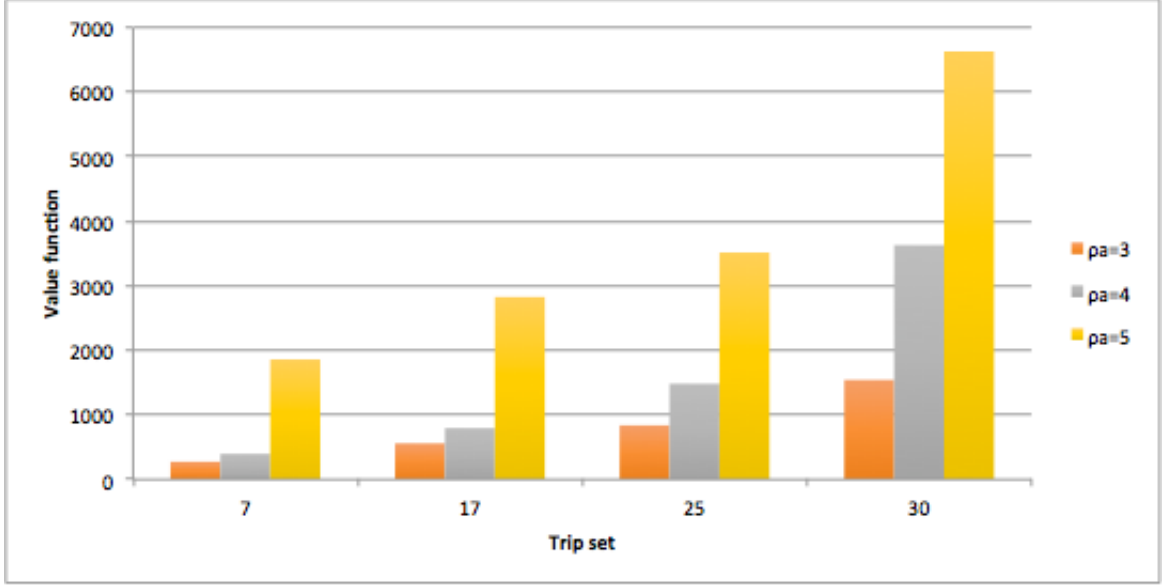


Figure 5.4: Value function trend for the different trip set T and $\rho_a = 3, 4, 5$ carriers

seconds, and 0.17 seconds in the three cases, respectively. It can be seen that, considering equation (5.9), if carriers A, B, C operate independently, $\phi(u)$ is zero, while in the collaborations settings AB, AC, BC, ABC it results that $v(s) > 0$ because the respective $G(u)$ are higher than the individual profits. Considering the results obtained, $\phi(u)$ increases as the size of the coalition grows, with the largest value corresponding to the grand coalition case ABC .

In Table 5.5 the individual profits of each carrier before and after the collaboration are compared, again for each scenario considered (i.e. 7, 17, 25 and 30 trips). By observing Table 5.5 it can be noted that each carrier profit increases thanks to the collaboration. By increasing the number of trips merged (highlighted in columns), profits increase as well. This property also reflects in the profit distribution between the carriers joining the alliance.

For what concerns the different allocation methods that have been tested, the results obtained are similar but not coincident; there are some little differences that reflect the possibility of having one or more acceptable solutions in the core and a different definition of fairness in each mechanism.

It can also be noted that, considering an initial balanced trips assignment (binary parameter Z_c^r), cost savings are similar for all carriers. If the initial assignment of trips is unbalanced, i.e. almost all trips originally belong to only one carrier, the profit allocation is different and is influenced by such original assignment. As shown in Table 5.6, if carrier A originally owns the majority of trips, the collaboration may impose him to serve a lower number of trips compared to the ones previously owned,

Table 5.5: Profit Allocation Comparison

Car.	trips	Pre Co.	Shap.	EPA	ACS	PGA	Nuc.
A	7	70.0	87.7	84.0	88.5	84.0	84.0
	17	150	189.8	193.3	188.8	193.3	193.3
	25	219	282.5	285.7	281.6	285.7	285.7
	30	487	528.7	543.7	526.7	543.7	543.7
B	7	68	91.3	91.0	91.3	91.0	91.0
	17	145	180.0	175.3	182.4	175.3	175.3
	25	228	275.5	271.7	276.6	271.7	271.7
	30	498	505.2	496.7	506.3	496.7	496.7
C	7	63	95.2	99.0	94.3	99.0	99.0
	17	145	188.3	190.3	188.7	190.3	190.3
	25	204	280.0	280.7	279.8	280.7	280.7
	30	479	507.2	500.7	508.0	500.7	500.7

so gaining proportionally less compared to the other carriers. On the contrary, carriers *B* and *C* would be assigned more trips and consequently would gain more. So, in this case the cooperation would result more convenient for carriers B and C than for carrier A.

Table 5.6: Profit Allocation with A owning the majority of trips

Car.	trips	Pre Co.	Shap.	EPA	ACS	PGA	Nuc.
A	7	80.0	80.6	80.4	80.5	80.0	80.0
	17	197.0	207.8	200.3	200.2	212.4	212.4
	25	306	312.2	315.5	312.5	310.2	310.2
	30	608	610.5	613.4	614.5	613.5	613.5
B	7	68	100.1	120.0	121.3	120.0	121.2
	17	135	180.0	180.3	180.4	185.3	185.2
	25	228	284.0	283.7	273.6	281.7	281.7
	30	433	505.2	496.7	506.3	496.7	496.7
C	7	50.0	115.2	120.0	124.3	124.0	124.0
	17	110	190	192.3	198.7	196.0	196.3
	25	180	295.2	292.7	290.8	291.5	291.6
	30	400	510.1	510.7	505.0	508.4	508.4

Finally, in table 5.7 is presented the comparison between the mathematical model proposed in this Thesis and the Game Theory Methods. Results are presented for different set of carrier alliances, varying the dimension of ρ_a , and of the trip set

T , in terms of % increase of profit S^r . It can be stated, that, when deciding how to share carrier profits, it is hard to say which allocation mechanism is better than the others, because they provide similar results. This underlines the fairness of such allocation methods and the fact that collaboration is definitely convenient for carriers. In practice, a method may be chosen based on an agreement between carriers before the collaboration starts.

Table 5.7: Comparative analysis among profit allocation schemes

Trip #	Car.	Initial Profit	Ad hoc met.(%)			Shapley (%)			EPA(%)			ACS(%)			PGA(%)		
			$\rho_a = 3$	$\rho_a = 4$	$\rho_a = 5$	$\rho_a = 3$	$\rho_a = 4$	$\rho_a = 5$	$\rho_a = 3$	$\rho_a = 4$	$\rho_a = 5$	$\rho_a = 3$	$\rho_a = 4$	$\rho_a = 5$	$\rho_a = 3$	$\rho_a = 4$	$\rho_a = 5$
		S_0^r	S^r	S^r	S^r	S^r	S^r	S^r	S^r	S^r	S^r	S^r	S^r	S^r	S^r	S^r	S^r
7	A	70	21	8	3	20	9	3	19	10	3	20	10	3	17	9	3
	B	68	25	13	4	25	12	4	25	13	3	25	13	2	25	12	3
	C	63	34	5	2	34	6	2	36	7	2	33	6	1	36	8	2
	D	53	-	4	1	-	5	1	-	4	0	-	5	1	-	5	1
	E	53	-	-	2	-	-	1	-	-	2	-	-	2	-	-	1
	S_{tot}	300	27	7	2	26	8	2	27	9	2	26	9	2	26	9	2
17	A	153	14	12	12	15	11	11	13	12	11	12	11	11	14	11	11
	B	158	20	12	4	20	12	4	19	12	3	19	12	2	17	13	5
	C	144	25	11	3	23	11	3	24	11	3	21	11	2	24	12	2
	D	142	-	15	10	-	14	10	-	13	10	-	12	9	-	9	8
	E	150	-	-	2	-	-	2	-	-	1	-	-	1	-	-	1
	S_{tot}	136	20	13	6	19	12	6	19	16	2	17	12	5	18	11	5
25	A	219	19	26	31	20	26	31	21	26	31	22	27	30	23	26	29
	B	228	20	30	32	19	31	32	20	29	32	18	29	33	16	30	31
	C	204	22	21	33	22	20	32	23	21	32	23	20	32	22	19	32
	D	217	-	8	16	-	9	11	-	9	10	-	10	10	-	9	9
	E	239	-	-	5	-	-	2	-	-	2	-	-	1	-	-	1
	S_{tot}	1107	20	21	23	20	22	22	21	21	21	21	22	21	20	21	20
30	A	487	15	20	25	14	20	25	10	19	24	13	18	24	10	18	24
	B	498	15	20	24	13	20	23	12	11	23	14	15	23	13	13	25
	C	479	4	24	23	6	23	24	4	20	24	6	21	19	4	21	22
	D	490	-	16	17	-	16	18	-	15	19	-	16	16	-	15	18
	E	498	-	-	20	-	-	19	-	-	19	-	-	18	-	-	19
	S_{tot}	2452	12	20	22	11	20	22	9	16	22	11	18	20	9	17	22

Chapter 6

Conclusion

In this Thesis, the possibility to apply horizontal collaboration between truck carrier operators has been analyzed with the purpose of reducing inefficiencies and increase carrier's profits, thus limiting negative externalities to the community, such as congestion and environmental pollution.

Applying collaboration schemes in a selfish environment as the road carriers is, is more than challenging, but it should be one of the few solutions able to reduce or even better to stop the failure of the sector.

Although in the present thesis the focus is the horizontal collaboration between truck carriers the horizon of collaboration should be extended to all stakeholders of logistic chain of transport of goods (vertical collaboration).

To deal with the goal, an optimization approach has been applied with the objective of maximizing the cost saving of a coalition of road freight transportation carriers sharing their demands. This goal is pursued by combining trips together in the same route, by suitably reassigning combined trips to carriers and by properly sizing the carriers coalition dimension.

The optimization scheme proposed is composed of three steps:

The first phase of the proposed scheme combines multiple trips in order to maximize cost savings, performing all trips, taking into account specific constraints, such as the driving hour restrictions of truck drivers, independently from the original ownership of the trips. As a consequence, trip combinations allow to reduce the number of empty trips performed and, so, to gain environmental and road congestion benefits. Different approaches have been formulated, implemented and compared on different instances and scenarios, by varying the typology of trips, trip due-dates and node time windows. Real data provided by transportation companies that operate in the hinterland of the Italian ports of Genoa, Savona and La Spezia have been used to test the proposed optimization schemes. The results obtained have shown that the variable size case is the most effective one. Its superiority towards the other approaches is

twofold: it allows to maximize the total cost savings by reducing the number and length of empty trips, and, also, it optimizes truck utilization since the number of routes needed to fulfill the whole trip demand is significantly reduced. Furthermore, the variable size case proved to be the most effective method in terms of CPU time for computing the optimal solution. The interesting results obtained - both in terms of cost savings and truck usage - appear to be useful both for the business sector, i.e. truck companies, and for the social community. Moreover, the simplicity of the proposed mathematical optimization model allows real carriers to simply implement and use it. This is particularly beneficial for small-sized operators - that correspond to the majority of the market - which neither are familiar with mathematical techniques nor can afford big investments in technology.

The second phase assigns the combinations found at the first step to carriers with the goal of maximizing the coalition profit. To achieve this goal, have been applied two profit distribution strategies: firstly has been proposed an original optimization method able to properly assign profits to carriers by the assignment of trips, taking into account the original property of the trips; secondly, to validate this approach, Game Theory methods of profit sharing have been applied.

The two first phases are realized through the solution of ad-hoc optimization problems having the structure of a MILP and an ILP, respectively.

Finally, to properly size the coalition, the second original optimization problem is solved several times by considering different coalitions in order to find out the coalition type that further maximizes the total profit. In this phase, a coalition management cost, depending on the number of carriers acting in the coalition, is considered.

Experimental results applied to a real case study have illustrated the benefits of the collaboration to maximize both individual and total carriers' profit. It can be noted that the results of the last phase of the proposed scheme are influenced by the type of coalition costs adopted. The simple case in which these costs have a linear structure has been considered. The obtained results are promising but quite straightforward. This suggests to try different (maybe more realistic) cost structures as, for instance, piecewise affine concave structures, or structures including a saturation term. This is the objective of present research in which, the same optimization scheme is maintained and only the last step is varied (by considering different costs). Furthermore, experimental results have clearly illustrated the effectiveness of the collaboration schemes both from the global and individual profit maximization points of view. In addition, all the allocation methods proposed, both the GT methods and the original mathematical formulation, present quite similar results that underline the fairness of such methods confirming that collaboration is always convenient rather than individual approaches.

The way forward

To conclude this Thesis it is necessary to point out some limitations to the collaboration that should be overcome. The reasons identified were in two main areas that impact each other strongly:

1. lack of structures and nurturing culture for suitable communication and collaborative work between different industry organizations;
2. IT practices and systems that are insufficient to support collaborative work that is effective in improving productivity.

There are only few examples of structures capable of fostering required levels of contact, trust and transparency for effective collaboration across organizations with the objective to improve revenues. This collaboration structure should be extended to all the port stakeholders to better define and follow common objectives. Once more, to be effective, there is the need to have the integrity to manage and disperse information and data that may be important for productivity improvement but also may be considered commercially sensitive. Linked to data management should also be defined platforms and tools to manage complexity, handle potentially large quantities of data, and allocate and apply that data in the correct manner have a central role. Such platforms and tools need to be capable of sharing data in an automated fashion while ensuring proper handling of sensitive elements. The collection, management and sharing of data in a timely and purposeful manner as a key to be improved to enhance collaboration. In the current business culture, ownership and control of data frequently is seen as a competitive advantage and there is a dominant fear that sharing it could expose companies to more commercial risk as well as undermine negotiating positions by revealing weaknesses or strengths.

Closely related to the issues around data, adoption of and adherence to IT best practice isn't common in truck carrier companies today, limiting opportunities for transparency and collaboration and large-scale innovation.

Attributed apathy toward working together to improve productivity to a perception of diffused value or value that is not directly attributable or equally shared. A spread fear is that some key participants in collaborative projects may input considerable effort and resources toward improving productivity but a larger share of the benefits of the work may go elsewhere. This is a key aspect faced on this Thesis: every participants of the collaboration take part in a different way and for this reason, also revenue and costs are distributed in the proper way.

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