MASTER

Design of decision support models for FTL and LTL shipping

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Design of Decision Support Models for FTL and LTL shipping

by

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ABSTRACT

This research project was conducted, to partially fulfil the requirements of the master degree of science in operations management and logistics at the Technical University of Eindhoven and, it took place in the headquarters of Jan de Rijk company, a Dutch LSP, located in Roosendaal.

Target of the research was the development of two decision support models that would provide high quality of decisions/suggestions to the planners of the company, during the planning process. On daily operation, planners at Jan de Rijk have to consider multiple parameters and variables of shipments, to design efficient transportation plans. Thus, the two models that were developed, took into account many aspects and, they can offer cost saving, rapid and still efficient decisions regarding FTL and LTL shipping. Using the information that could be sourced from the two tools created, planners can be able to compare and assess various scenarios by altering or updating the main parameters in the models, while satisfying cost savings and on time performance, increasing utilization of assets, and reducing emission levels.

EXECUTIVE SUMMARY

The outsourcing of logistics activities to service providers (LSP) has become an integral part of supply chain, offering new opportunities and challenges to trucking companies. These companies, in turn are responsible of offering reliable, cost efficient, innovative and sustainable logistics solutions to their customers, regarding transportation and distribution.

The research project, that is presented in this paper, was conducted in a Dutch based leading LSP, Jan de Rijk (JdR), and it is related to the operations inside this specific company. On a daily basis, planners of JdR are responsible for designing the most efficient plans in terms of cost, service level and customer satisfaction, in order to fulfil freight requests. Furthermore, they have to handle a huge number of pulling (trucks) and pulled units (trailers), while unexpected events (bad weather conditions, strikes, freight shifts, etc.) could further complicate the planning process. Thus, target of this project was to develop a model that if implemented in the advanced planning system (JPLEXS) of the company, it can offer rapid high quality decisions to planners during the designing of a transportation plan.

JPLEXS currently supports the matching between pulling and pulled units, as well as the matching of driver to pulling and pulled units; anyhow many other aspects that have a crucial role during planning are not considered. Specifically, a limited amount of constraints are taken into account by the system, making the planning even more challenging, since planners have to consider:

- Travelling times between locations
- Matching of freight to pulled units
- Consolidation of small sized freights
- Decisions regarding empty running
- Time windows of shipments
- Decisions regarding the assignment of shipments to third parties (charter)
- Repositioning of assets

Although the initial goal was to develop a model that would address issues related to less-than-truckload (LTL) shipments, it was found significant to further extend this project by designing, and specifically transforming the model that is already developed in the company, which takes into account only full-truckload (FTL) shipments, to edit infeasibilities found. Additionally, a green extension, related to reduction of fuel consumption, was included in the objective function of the FTL model. Consequently, two models were finally developed, VAPCI-G which considers only FTL and, CDPHC that could be used for decisions regarding LTL shipments.

Tables 1 and 2 present an overview of decisions that can be obtained from the models, if they applied in JPLEXS. As it can be observed, the amount of decisions that need to be taken by the planners could be reduced significantly. Thus, planners will be able to investigate and evaluate various scenarios, by altering parameters, like freight requirements or available capacity of vehicles, during different time periods. Examining these models with real case studies, it was discovered that not only better transportation plans and manpower savings can be attained, but also more benefits are generated in diverse aspects. These benefits are directly associated to optimized company's

performance, since the models can deliver cost savings, higher service levels and increased customer satisfaction.

Decisions supporting FTL	Planner	VAPCI-G
Driver allocation	✓	
Travel times		✓
Matching of freight to pulled unit		✓
Empty running		✓
Repositioning of assets		✓
Assignment of shipments to charter		✓
Reduction of fuel consumption		✓

Table 1: Distribution of decisions if VAPCI-G is applied to JPLEXS

In particular, VAPCI-G manages to attain cost savings of about 16%, while the ones of CDPHC amount to 14%. Hence, planners who currently have no visibility on costs and/or revenues during the decision making process, could highly exploit the decisions generated by the two models, which give a coherent picture of activities to the planners. The computational time that is needed to obtain solutions cannot be ignored, since the models generate solutions rapidly. Consequently, higher flexibility during the decision process can be attained. In addition, in an era where environmental regulations force trucking companies to take measures to reduce their environmental burden, both tools (in)explicitly facilitate reduction of emission levels, using better allocation decisions.

Except from the above and considering solely the model that was developed for LTL shipping, higher utilization of assets can be obtained (on average 96%) by consolidating appropriately small size shipments for multiple destination points and, avoiding movement of semi filled vehicles in the network. Further, on time performance is another aspect that should be emphasized, since a major challenge faced in LTL shipping consists in the control and synchronization of multiple shipments' delivery windows. In general, during the planning of LTL more than six distinct characteristics of shipments (destination of shipment, type of commodity, delivery deadline, etc.) have to be considered, evaluated and combined by the planners, leading to increased complexity in the decision making. In such cases the model can offer competitive advantage to the company, since various scenarios and updated information can be included, combined and assessed by the planners, offering higher flexibility, rapidity and manpower savings during the planning process.

Decisions supporting FTL	Planner	CDPCH
Driver allocation	✓	
Travel times		✓
Matching of freight to pulled unit		✓
Consolidation of shipments		✓
Handling of semi filled trucks		✓
Assignment of shipments to charter		✓

Table 2: Distribution of decisions if CDPHC is applied to JPLEXS

The research project, that was conducted in the headquarters of JdR in Roosendaal, proved that implementation of both models in the planning system of the company can positively influence the overall performance of JdR and, in particular facilitate the challenging planning process. The two models consider two distinct aspects of shipping, FTL and LTL, and they are able to come up with decisions that cover the whole spectrum of services that are offered by the trucking company. Both models, having as common factor the cost structure, can offer high quality of decisions that could collectively result into:

- Significant cost savings
- Reduction of planning time
- Better allocation decisions
- Reduction on empty running
- Increased utilization of assets
- On time performance
- Reduction of emissions
- Manpower savings

Consequently, the implementation of such models in JPLEXS, can provide planners optimal suggestions during planning, reducing simultaneously the time needed for generating decisions. It should be explicitly referred though, that the target during the development of both models had never been to cancel planners' activities. The aim was to facilitate their tasks, by offering two models that could generate decisions, which can be used as indicators for designing the most efficient plans, in terms of costs and customer satisfaction.

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ABBREVIATIONS

3PL	Third Party Logistics Provider
4PL	Fourth Party Logistics Provider
APS	Advance Planning System
BC	Board Computer
CDPHC	Consolidation and dispatching problem that considers heterogeneity and charter decisions
CMR	Form/contract for the international carriage of goods
ESB	Enterprise Service Bus environment
EEA	European Economic Area
EU	European Union
FFM	Freight Forwarding Request
FTL	Full Truckload
GDP	Gross Domestic Product
GHG	Greenhouse gas
IT	Information Technology
JdR	Jan De Rijk Logistics
JPLEXS	Jan De Rijk Planning, Execution and Scheduling
KPI	Key Performance Indicator
LSC	Logistics Service Client
LSP	Logistics Service Provider
LTL	Less Than truck Load
TMS	Transportation Management System
VAP	Vehicle Allocation Problem
VAPCI	VAP that considers charter decisions and idle costs
VAPCI	VAP that considers charter decisions, idle costs and fuel reduction (green)
ULD	Unit Load Device

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INTRODUCTION

Supply chain activities have become an essential part of organizations' operations in an era where globalization creates new opportunities and challenges for manufacturers, suppliers and retailers. Physical distribution constitutes a fundamental part of supply chain and, its importance has increased dramatically as the logistical flow of goods to customers strives to become more efficient [1]. In the following sections of this chapter firstly some facts and figures regarding road freight transportation will be presented, followed by an analytical description of the structure and activities of the company, where this project took place. The scope and methodology, that adapted for the research, are described at the end of this chapter.

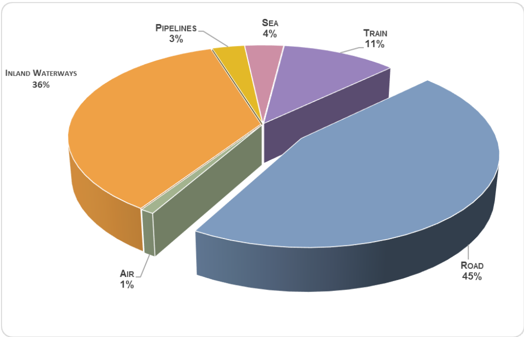
1.1 ROAD FREIGHT TRANSPORTATION

Global economy started recovering after the impact of 2007-2008 financial crisis, which has been considered by many economists as the most severe recession since the Great Depression. During the second half of 2013, global activity strengthened and, is predicted to improve further during 2014-2015. Global growth is expected to slightly increase during 2014, around 3.7%, rising to 3.9% during 2015. This happens mainly due to economic recovery in the advanced economies (Table 3), since in emerging markets and developing economies the growth is projected to move modestly[2].

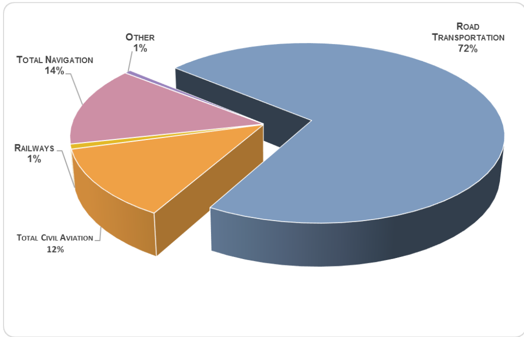
	Real GDP			Consumer Prices			Current Account Balance			Unemployment		
		Projections			Projections			Projections			Projections	
	2013	2014	2015	2013	2014	2015	2013	2014	2015	2013	2014	2015
Advanced Economies	1.3	2.2	2.3	1.4	1.5	1.6	0.4	0.5	0.4	7.9	7.5	7.3
United States	1.9	2.8	3	1.5	1.4	1.6	-2.3	-2.2	-2.6	7.4	6.4	6.2
Euro Area	-0.5	1.2	1.5	1.3	0.9	1.2	2.3	2.4	2.5	12.1	11.9	11.6
Japan	1.5	1.4	1	0.4	2.8	1.7	0.7	1.2	1.3	4	3.9	3.9
United Kingdom	1.8	2.9	2.5	2.6	1.9	1.9	-3.3	-2.7	-2.2	7.6	6.9	6.6
Canada	2	2.3	2.4	1	1.5	1.9	-3.2	-2.6	-2.5	7.1	7	6.9
Other Advanced Economies	2.3	3	3.2	1.5	1.8	2.4	4.8	4.7	4.3	4.6	4.6	4.5

Table 3: Real GDP, Consumer Prices, Current Account Balance, and Unemployment for Selected Advanced Economies(annual percent change)[2]

Transportation of freight is a main component of the world economy, and as many other domains, had been significantly affected by the over mentioned recession. Nonetheless, not all the transportation modes were influenced in the same way. Freight transportation through sea and air seems to be preferred, reaching a new high, while road and rail transportations are still struggling to improve their levels, which yet remain below the pre-crisis levels [3] (Figure 1, (a)). However, the choice of the appropriate mode is more complicated than how it might look, and several factors can influence its decision. The economic and practical advantages that road transportation offers, both for direct shipments and intermodal freight transportation, are the main reasons why this type of transportation remains the dominant and most widespread (in terms of use). The share of sea and especially air transportation (Figure 1, (a)) still cannot be compared to the roads mode. The road routing networks are the ones that have been studied the most through advanced researches, proposing algorithms and heuristics for optimized handling of freight, truck and personnel. In addition, the variety in terms of type and size of shipments that can be served, offers a significant competitive advantage.



(a) Share of freight transportation modes in EU (%), based on ton- kilometers[4]



(b) CO_2 Emissions from Transport EU-27 by mode (share %)[4]

Figure 1: Road Freight Transport and Emissions by mode in European Union

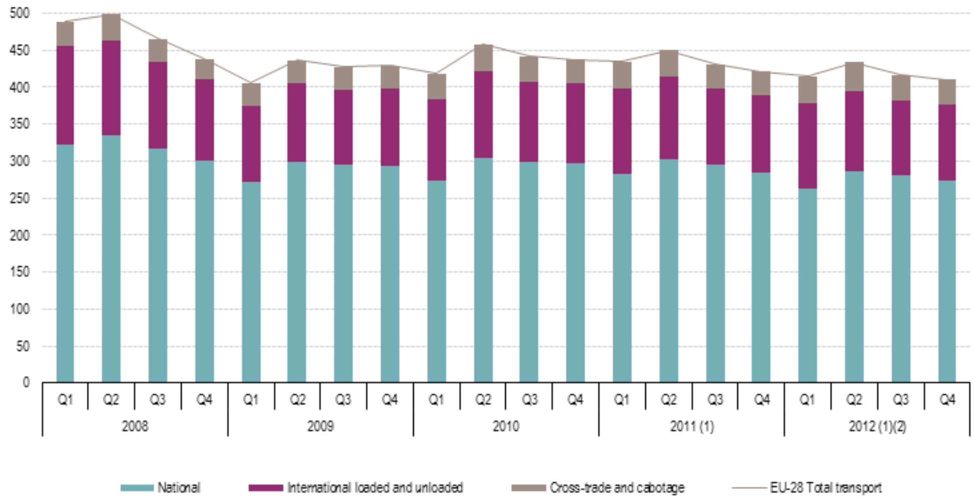
1.1.1 *European Figures*

Road transportation is essential for the economy of every country since it provides conveyance of raw materials, work in process and finished goods from business to business and from business to customers. The varieties of products that can be transferred along with the well-connected road networks are the main reasons why road remains the most popular mode of transportation. According to the transportation statistical pocketbook that EU [4] publishes every year: between 2007 and 2013 7.21 billion Euro was invested on road infrastructure (around 14.50 for every person in the EU), while the volume of freight transported via road during 2013 was close to 1667 billion tone km (tkm) [5]. It must be noted that the above numbers significantly surpass the ones that correspond to the other transportation modes. According to the report of European Environmental Agency (EEA)[5], which was published on December 2013, "road haulage accounted for 76% of total freight movements by road, rail and inland waterways within the EU-28 in 2011" (Figure 2). However, between 2010 and 2011 road freight demand varied across the different EU members, since in the EU-15[1] the road freight transportation fell by 2.3%, while in the EU-13[2] grew by 2.1%. Furthermore, road freight transportation offered around 2926.4 thousands job positions with 581,462 enterprises competing around Europe[4], even if the negative side effects of road transportation cannot be ignored. The share of road on GHG emissions far exceeds other modes, with 72.1% of the total greenhouse gas (GHG) emissions from transport in Europe (accounting for about 876.6 million tons CO_2 equivalent) to be blamed on road transportation, during 2010 (Figure 1, (b)).

1.1.2 *Trucking Industry Operation*

Trucks and trailers represent the most used ways of goods transportation over land, providing a vital service for global economy. A variety of light, medium, heavy and very heavy trucks exist today with a diversified range of trailers (flat bed, container, lowboy, water, fuel, chemical trailers etc.), in order

1 Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom.
2 Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, Slovenia.



(1) UK: 2010 instead of 2011 and 2012.
(2) LU: 2011 instead of 2012.

Figure 2: EU-28 quarterly road freight transport (billion tkm)[6]

to satisfy almost any products transportation demand. Information and Communication Technologies (ICT) along with various researches, which have been conducted on this domain, brought significant benefits and insights to the trucking industry operations, although there are challenges to be faced. A huge amount of companies compete with each other to achieve marginal profits; beside this issue, several more constitute impediment for further development, complicating more companies' operations. Internal and external costs, driver shortage/ retention, congestion, rapid evolution of technology and, obviously, governmental regulations are some of the most diffused. The governmental regulations, in specific, related to reduction of GGH emissions produced by vehicles, represent a huge concern nowadays. Governments have established legislations and fines for disconnecting, as much as possible, road mobility from its negative consequences.
The road networks are strongly developed through many terminals and intermediate stations providing a variety of services. Fixed terminal networks, which are called linehaul networks, are used by carriers for direct and indirect shipments. If we follow the classification that Chu (2004)[7] used, then the following types of terminals can be identified:

- *Origin/Destination satellite or end-of line terminal*: usually serve a small geographical area. They are used as sorting centers and loading facilities for outbound freight. From there, shipments are directed to breakbulk terminals.
- *Origin/Destination breakbulk terminals*: serve a large geographical area. From there, shipments are distributed to destination breakbulk terminals or direct shipping is happening to a destination satellite or to the customer. If consolidation of shipments is necessary, then freight from satellite terminals is concentrated in these spots.
- *Relay terminals*: usually they are breakbulk terminals or special facilities which are used as intermediate stations. When the destination between origin and destination is too long for a single driver, then the shipment relays on another driver in these centers.

A network that includes these stations is called hub-and-spoke network, but the above classification is not used by many researchers, and usually the only term that is found in the literature is origin/destination terminal, without further specifications. The path that each shipment follows through this network is determined by the load plan [10]. This plan specifies which stations should be used, which freight needs to be consolidated, how shipments should be distributed, and which load should be shipped directly. Generally the services that are offered by the trucking companies and influence the load plan can be classified on:

- *Truckload (TL)/ Full- Truckload (FTL)* shipments, and
- *Less-Than-Truckload (LTL)* shipments

The term *FTL* is used to describe individual shipments, which usually fill the entire trailer(s), while direct shipping is happening between origin and destination. No additional handling or sorting intervenes in this plan, so that corresponding costs do not occur. Typically, *FTL* includes customers who ship bulk, and the costs for hiring a larger truck are usually counterbalanced by the huge amount of goods shipped [8]. On the other hand, the term *LTL* is referred to shipments that do not fill an entire truck. It usually includes the shipping of small items, like parcel, or generally shipments, which weight less than 10.000 pounds, according to Interstate Commerce Commission (ICC)[8]. *LTL* shipping concerns not only regional carriers, who operate end-of line terminals, but also long-haul carriers. For economic reasons, mainly, various shipments are used to be consolidated in a trailer, leading to additional handling of the load on intermediate terminals [9]. Empty trips, idled capacity on lots, and rising energy costs are some of the features that can develop into negative economic consequences for *LTL* carriers, who operate on thin margins. These consequences additionally can cascade to other industries, influencing global or domestic economy; "for instance, empty trips may affect global food prices" (Hernandez, Peeta and Kalafatas, 2011) [10]. Furthermore, driver management is more challenging for *LTL* carriers, as many of them can be used for multiple consecutive load dispatches, creating extra costs and concerns about the driving hours allowed by regulations [8]. Shippers usually pay according to the amount of space they use on a truck, but special contracts and agreements (through negotiations) can be arranged between carriers and shippers. However, the freight on *LTL*-related services is priced significantly higher than on *FTL* [7]. According to Ozkaya, Keskinocak, Joseph, and Weight (2010) [9] *LTL* is a 34 billion industry in the US (EU corresponding numbers could not be found) representing a huge amount of the US GDP.

1.1.3 *Logistics Service Providers*

In addition to the aforementioned, a trend on the supply chain management, which has become common practice and has influenced the operation of trucking companies, is represented by the outsourcing of logistics activities to firms that are responsible to execute these services. Logistics industry has introduced several types of Logistics Service Providers (LSPs), where the most prominent are the 3PLs (third party logistics service providers) and 4PLs (fourth party logistics). 3PLs are external suppliers that perform all or part of a companys logistics functions, including: transportation, warehousing, distribution, and financial services [11],[12]. On the other hand 4PLs manage and direct the activities of multiple 3PLs, serving as an integrator [11].

1.2 JAN DE RIJK

1.2.1 *Company Description*

JdR is a Dutch based leading LSP of transportation and distribution services, committed to provide qualitative, reliable, cost-efficient, innovative, sustainable logistics solutions (including 3PL and 4PL solutions) for its customers[13],[14]. The firm was founded in 1971 by Jan de Rijk and Jacqueline de Rijk-Heeren, who remain the main shareholders of the group and serve on the Board of Directors. The international logistics provider has managed to achieve a consistent growth through the years, and as a result, its network has been expanded, by targeting the high-end industries, and its product portfolio has been diversified, by acquiring warehousing and developing Benelux distribution [13]. JdR's business culture is characterized by an informal, approachable organization, with sufficient development opportunities for its employees. JdR provides a variety of services including temperature controlled transport, intermodal solutions, international transport, warehousing, Benelux distribution, container transport, retail distribution, event logistics and forwarding. An overview of JdR's current key figures is given on Table 4.

Dimension	Numbers
Number of employees	approximately 1000 FTEs
Number of offices	26
Number of countries	15
Vehicles deployed	over 1000
Number of owned vehicles	500
Number of owned trailers	1200
Warehouse Capacity	90,000 m^2
Certifications	ISO 9001, ISO14001, HACCP, CCQI AEO, TAPA compliance
Revenue	167 million €(2011)

Table 4: Facts and Figures of JdR

As of 1972 the firm managed to become an important competitor in the field of international air transport, with a strong European network, and a strong niche player of Benelux distribution in the non-food retail segment. With warehouses in key locations, including Amsterdam (Schiphol), Beilen, Meppel, Eindhoven, Roosendaal and Swalmen, JdR offers an array of flexible warehousing and inventory management concepts, from a complete European Distribution Centre (EDC) to a combination of Regional Distribution Centers (RDCs) or satellites and with Value Added Services (VAS). The firm offers total integrated logistics services at the highest quality and at competitive costs to its clients and, it constitutes an innovator in the field of logistics management services.

1.2.2 *Industries Served*

The products of the industries that JDR deals with are characterized by time criticality and, they have a high value of density. In addition to these specificities, it needs to be taken into account that each sector has its own unique characteristics and requirements. During all these years of experience, the firm has gathered sufficient in depth knowledge for many of these products, specializing itself in a wide range of industries. In particular, JdR has developed significant proficiency in offering high quality services for the following sectors:

- Aerospace (i.e., aircraft engines and components, propulsion units etc.)
- Automotive (i.e., motor vehicle body manufacturing, gasoline engines, vehicular lighting equipment etc.)
- Duty Free (i.e., edibles, luxury commodities, cosmetics etc.)
- General Cargo (consumer goods, containers)
- Healthcare
- High- Tech (i.e., electrical machinery and apparatus, transport equipment etc.)
- Perishables (fresh logistics, pharma)
- Retail
- Tobacco

- Air Cargo (includes all the aforementioned industriesproducts)

JdR due to its asset based vision, dedicated employees and strong IT system, is able to deliver high quality services to any of the above sectors. It should be noted that the company especially pioneered and addressed its focus into road feeder services for the emerging air cargo industry in Europe. A wide array of daily scheduled and flexible FTL and LTL feeder services have been established throughout Europe. The logistics company offers many services, including regular daily airport-to-airport distribution as well as direct pick-up (door-to-airport) and direct delivery (airport-to-door) operations.

1.2.3 *Logistics Solutions*

JdR's portfolio contains a variety of supply chain solutions for the different industries. The organization is small enough to dedicate attention and commitment, but at the same time big enough to deliver a totally integrated package of logistics solutions with a unique network to its customers. The idea is that customers use JdR as a competitive logistics advantage, lowering their supply chain costs by applying one or more from the following logistic solutions:

- Control Tower: independent trucking desk, inventory management and materials handling, 3PL and 4PL solutions network.
- Forwarding: own forwarding department, customs capabilities.
- Special Projects: i.e., theaters and exhibitions, European sporting events, car racing / motoring events.
- Engineering: network improvements, design of special trailers, tailor made solutions.
- Consultancy: global projects based on experience and knowledge; achieve efficiencies in supply chain processes
- Event Logistics: dedicated operation with crew and equipment, handling of European projects and events.
- Innovative Projects: e-freight, CO_3, 4C4D, green-rail, HTS and Healthcare logistics.

1.2.4 *Fleet Description*

For most logistic service providers (LSP) operating without a private truck fleet is unimaginable, since high levels of efficiency, sustainability and customer satisfaction can be attained. Being one of the largest asset-based international transport companies, JdR deploys a diversified fleet of vehicles, trailers and semi-trailers (including trailers and road trains, mega- and standard trailers, box- and curtain-sided trailers, roller-bed and flat floor, low-loaders and trailers with slide- and adjustable roof for out-of gauge type of cargo) and, it continuously invests on improvements of its equipment-portfolio. Standardizing the vehicle platforms that comprise a fleet, offers several benefits (i.e., improved maintenance servicing), thus the company has chosen a small number of carefully selected suppliers. Moreover, it provides a variety of security solutions with tailor made equipment, since every action of assets (truck and trailers) is closely monitored to minimize risks and ensures safe transportation. Customers currently can select among a fleet of over 550 motorized vehicles and over 750 trailers and semi-trailers, choosing the ones that better satisfy their demand. As already stated, one of the most competitive advantages of the company is the road feeder services in the emerging air cargo industry in Europe, which offers a large fleet of air freight solutions. In particular, over 80% of the assets are equipped with air freight roller-beds and it is by far the largest part of the fleet low-deck (950mm fifth wheel

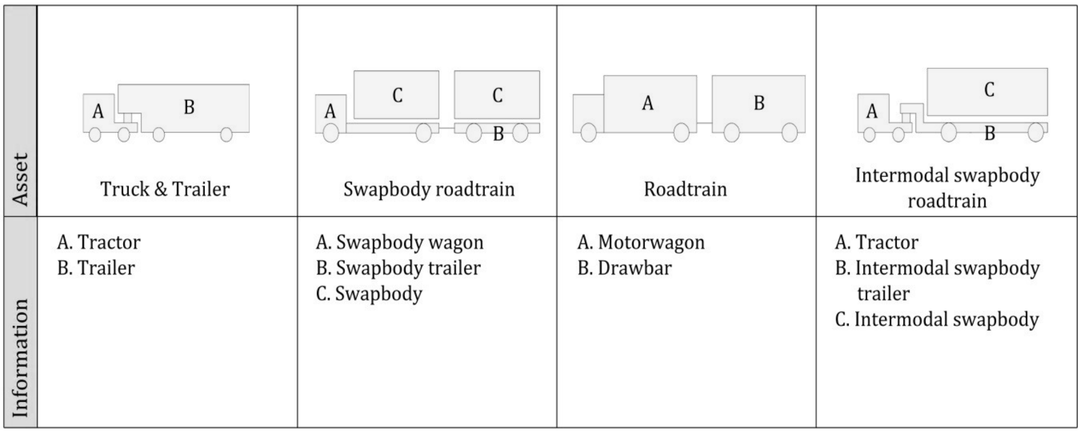


Figure 3: Description of JdR's fleet based on the characters and components of the company's assets

height). Roller-beds allow better handling.and enable safer unloading of the pallets or containers that are used on air cargo industry; namely ULD[3] (Unit Load Device). Figure 3 provides an overview of JdRs fleet.

1.2.5 *Transportation KPIs*

Key Performance Indicators (KPIs) are financial and non-financial metrics that organizations use in order to estimate and fortify how successful they are, with the aim of establishing long lasting goals [16]. As part of its company strategy, JdR has established three important performance criteria, specifically:

- 80 % use of loading meters per vehicle (load factor, loading meters)
- achieving more than 10,000 km per month per driving unit (running kilometers)
- on-time performances according to the specifications that the customers require (punctuality)

Besides the three above principles, which are mainly cost-driven, and rule operations and planning, a list of other performance indicators has also been defined. This list includes the following KPIs:

- Empty running operations (%)
- Empty running kilometers (%)
- Operation factor (km/operation)
- Fuel efficiency (litre/km)
- Emission efficiency (gr CO_2e/tkm)
- Vehicle time utilization (%)
- Transport content (km/ton)
- Transport efficiency (ton km/ vehicle km)

3 ULD is a pallet or container that is used to load luggage, freight, and mail on different kind of aircrafts. It allows a large quantity of cargo to be bundled into a single unit for avoiding delays and unnecessary effort[15].

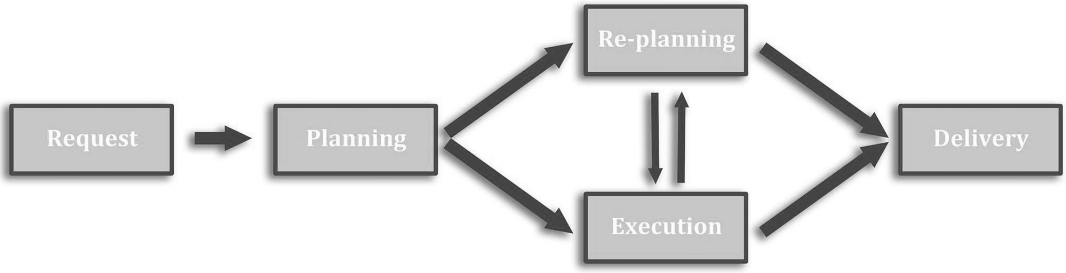


Figure 4: The transportation planning process at JdR

1.2.6 *Planning Process*

In general, the transport planning process at JdR consists of three basic processes: Planning, Execution and Completion (Figure 4). Within these processes the stakeholders are the Logistic Service Clients (LSC), the Transport Service Provider (JdR), the Third Party Logistics Provider (3PL) and the Transport Network Manager [17]. The above planning processes are applied both for FTL and LTL shipping, but some special features of LTL (i.e. consolidation of shipments) have always to be taken into account. The following part describes in detail each of these processes.

Planning(Offline Planning)

In this stage, the demand order is determined via an order entry customer support desk (i.e., phone) and several Electronic Data Interchange (EDI) based channels (i.e., email, website, etc.). JdR, being always a pioneer in its domain and trying to offer the highest satisfaction to its customer, has designed an extension of this process, a web-based application, which is currently under development. The incoming requests are entered into a Transport Management System (TMS) which is connected to an Advanced Planning System (APS) called **JPLEXS**. The available assets, the freight demand and the status of logistic activities are visible to the planners via JPLEXS. As soon as the transport requests are visible on the APS, the central planning department can start the actual planning process [17]. In general, this process starts three hours ahead of execution and it has to be noted that the requests that are taken into account each day are the ones that are visible before a defined point of time (usually before 01:00 pm). From this point and after customers are also able to track the status of their requests, since they are visible in a web-based application.

During the development of a transport plan generally two different perspectives are used by planners at JdR: truck or trip (virtual truck). In the first case planners have available assets and seek to match them with orders (own and/or external), while in the later one orders have been placed and they try to match them with assets (own and/or external/charter) for the execution of transports [17].

The planning process combines several freight requests with the availability to combine assets into a trip. The availability of assets in JdR is determined via the principle of a rolling road capacity network. This principle determines the type of tours that are assigned to vehicles with two existing alternatives: closed tours and open ended deliveries. The first one refers to the case when a vehicle starts from a central station/ depot and returns, while in the latter situation requests are assigned continuously to vehicles through the network. An illustration of this network is offered on Figure 5. In this depiction distribution centers (DC1, DC2), trucks (A, B, C, D, E, and F) and their capacities are visible. The arcs represent specific routes that are executed by the trucks at certain locations, hence as can be seen (Figure 5), trucks A,D make closed tours while trucks B,C,E and F perform open ended deliveries. As long as freight demand occurs at a certain place at a certain time, planners are

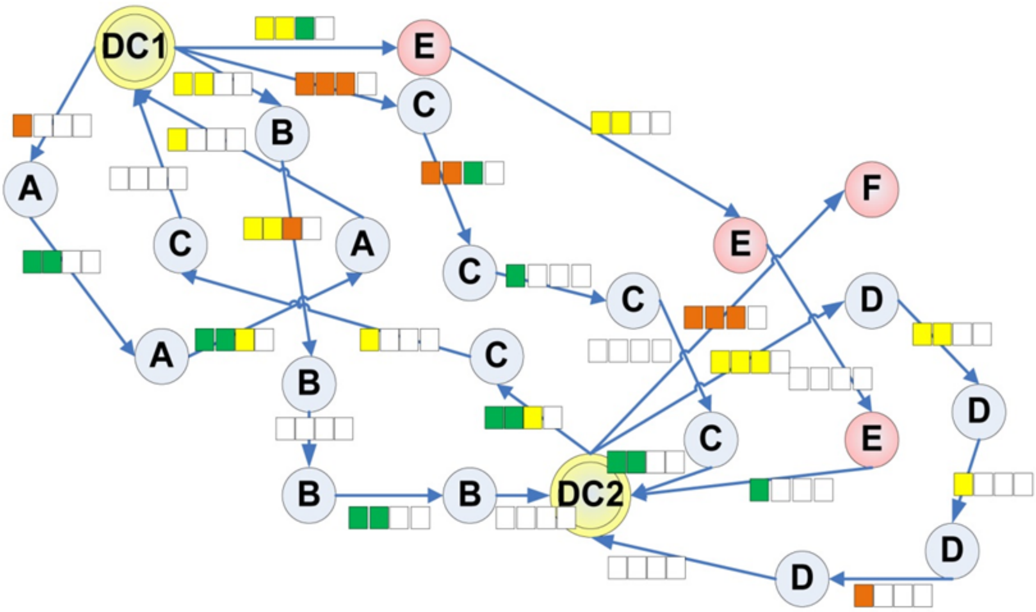


Figure 5: Rolling Road Capacity Network

responsible to generate an optimal planned route considering empty miles, freight loading meter(s), time windows of shipment, driving hours, type and quantity of fleet needed, positioning orders, optimal usage of loading capacity and (un)loading times. The resulted route includes the estimated times for loading and unloading, departures and arrivals, connections (train/ferry/plane), split shipment handlings and pulled unit changes.

It is significant to refer at this point that cargo, that is related to the leading role that JdR has on the European air cargo transportation, is generally divided between export and import. The export one is considered really important and special attention is needed during the development of a plan, since it is really strict on time and delays will have a significant effect on other parts of the supply chain. In contrast, import cargo is not so tight regarding time aspects and allows planners to generate more flexible plans.

In addition to the aforementioned parameters, planners are also responsible to determine a set of driver movement schedules for a set of loads during a given planning period. Driving regulations constitute a major constraint for generating these schedules, since drivers can only be used for a limited duration before they take a long rest. Drivers are allowed to be on the road for nine hours, while the maximum that are permitted to work are fifteen hours (including on the road and off the road operations that are they responsible for, like unloading etc.). Moreover, despite the fact that each driver is assigned to one truck and in the case of open ended deliveries there is usually no change of driver, there are specific locations around Europe that have been established where this can happen, if needed.

Besides all the above, which applies to both FTL and LTL shipping, some issues related to LTL shipping further complicates the generation of efficient plans, and so it demands more attention during the designing of a route. LTL is usually used to transport multiple products in small volumes to multiple clients, thus the utilization of the unused capacity inside the trucks (in-vehicle consolidation) can increase truck payload utilization and mitigate externalities (congestion, pollution, noise and accidents). Consolidation cannot be applied for every type of commodity since hazardous materials (explosive, flammable or combustible liquids, poisons, etc.) have to be co-loaded in different trucks than the non-hazardous ones. For this reason commodity codes have been established by JdR in order to distinguish the different types of products or product categories.

As long as the above restriction is considered, it is obvious that shipments with the same pick-up or delivery location can easily be combined. However this is not always the case and intermediate station(s) have to be visited in order to fully utilize vehicles unused capacity. These intermediate stations are related to multiple intermediate dock handlings, which in turn cause increased costs. Consequently, planners have to examine not only how to assign as many shipments as possible in the same fleet, but also how these shipments should be distributed (generation of transport plan for LTL). It is also significant to mention that simultaneous loading of freight and unloading of another one in the same location, for specific type of trailers (i.e., curtain-sided), is a possibility but not a rule. Specifically, in the case of the air cargo industry this is impossible, since the strict security controls do not permit that. For this kind of loads usually only a truck with one door can be used (roller-bed truck).

In the international transportation group, regions are divided among planners. Each of these regions is usually a country or a larger geographical area (i.e., Scandinavia), that allows planners to have visibility of all the demand requests in the area. Planners therefore have to explore all the available options and alternative routes in order to generate the most efficient load plans, in terms of cost and customer satisfaction. Whichever alternative is used, the cost of delivery is dependent on the distance that has to be travelled.

Execution

For LTL shipping one of the most important factors during execution is to load the right goods on the right truck and unload to the right customer, since multiple small volume products have to be delivered to diverse clients. The order in which the shipments are placed into the truck is also significant to avoid false unloading and save time on the intermediate stations. Verification of the cargo in terms of the amount of loading meters, weight, volume, damage etc. is an essential part of the activities during loading. Although drivers are not always physically doing the loading, they are responsible for this process. As it was already stated in section 1.2.6 drivers are allocated to trucks by the planners and usually they are informed in the last two hours before the loading should take place. During the execution of a delivery they have also to gather the several waybills[4] and make sure that the appropriate signatures are on the documents [17].

In addition, planners at JdR are responsible not only for the generation of a route but also for the execution/compliance of it based on real-time data both for FTL and LTL shipping (online planning). Each vehicle on JdR is equipped with a board computer[5] (BC) that offers real time information for the trip. This information is updated continuously and used by a specific group of planners, called truck-planners who are assigned to recalculate the already calculated times based on real time data. Whenever these re-calculations between original and actual plan lead to inconsistent results, new decisions regarding the load plan have to be determined by the planners [17]. Generally these inconsistencies concern time dependent variables since different arrival or unloading times may result or customers time windows are not satisfied. JdR uses an enterprise service bus (ESB) environment to process and exchange all this information between several IT systems and the BCs from the JdR assets.

Completion

After the freight has been delivered one of the most important aspects of the completion is the waybill getting to the freight administration of LSC. Drivers have special drop-points for returning

4 Document issued by a carrier giving details and instructions related to the shipment of a consignment of goods

5 Key features of BC: trip and hour registration, trip planning, track and trace, truck navigation, messaging traffic, fuel consumption registration and the possibility to measure the drivers driving style [18]

all the logistical documents back to the transport completion department of JdR [17]. JPLEXS is automatically updated and planners can assign new freight requests to the available assets. The orders that have been served remain on JPLEXS for 3 weeks and after that, they are stored at TMS, where they can be used to provide an invoice of the delivered orders.

Use of Charter

In many cases JdRs own assets cannot be used (for whatever reason) and assets are requested from other third parties (3PLs), called *charters* [17]. JdR has information for about 3,000 charters, so finding some kind of quick access method is essential. The process is done via heavy telephone interaction or email and can take up to six hours. Basic criteria for choosing a charter are the cost and the quality of service. Usually the cost of the charter is more than the one that JdR can charge for the shipment, so if it is possible the price is agreed upon based on previous jobs. After the price has been agreed, terms and conditions are set and the form/contract for the international carriage of goods (CMR) is signed.

It has to be noted that JPLEXS system needs real-time information from 3PLs to integrate them to the planning process and currently this is not possible during execution. As a consequence JdRs planners cant affect this process, since they do not have access to the information from BCs installed in 3PLsvehicles and are informed once a day for the evolution of an order. When the freight has been delivered, the waybill is getting to the freight administration of the LSP and the signed CMR is returned to JdR by the charter. A special case that is related to LTL shipping is the so called Expedition. This case is referred to the way that leftovers LTL are handled by planners at JdR. Leftovers LTL are shipments that do not fit in any truck and, for which no optimal plan can be made. If a charter could not be found, and JdR has been committed to the customer, then its own assets should be used for the distribution. However, when there is a chance for a truck to deliver a leftover LTL and return back to the depot as FTL for instance, then JdR can decide right away to perform the delivery with its own assets.

1.2.7 *Re-planning (Online and Offline)*

Besides all the aforementioned, it is likely that unexpected situations might occur during logistics or transport operations leading to disruptions in the supply chain with subsequent operational and financial risks; such situations are known as Events. Four general sources of unexpected events have been identified [17], [19], [20], [21] as can be seen on Table 5, where their source and characteristics are displayed. However, apart from this classification, these events can also be distinguished based on their predictability of occurrence. Some of them are highly unexpected and hard to be controlled beforehand (i.e., natural disasters) and others exhibit a repetitive pattern that can be predicted to a certain extent and thus there is existing information that can be taken into account during the planning process. Because the term (re-planning) is mainly used to describe re-planning during online planning, re-planning and execution on Figure 4, are preceded by offline planning and a feedback loop (due to information exchange between planners and truck drivers), through the real-time data that is offered via BC has been added between re-planning and execution (online planning).

However, re-planning is not only referred to online but also offline planning. It is common for planners, during offline planning, to modify already created transport plans in order to make the most efficient and profitable use of assets. As it was discovered during the first weeks in the company, almost half of the shipments each day need re-planning of routes and reallocation of shipments and drivers. Planners presently use mainly their experience to cope with such situations and decide how to re-plan current and subsequently future situations. Beside that, it is important to mention that

Source	Characteristic
Human Failures	Carelessness (speed limits, risky overtaking maneuvers, driving in a state of over-fatigue, etc.) Health Issues (sickness, circulation problems, heart attack, etc.) Miscellaneous (strikes, scheduling mistakes, inaccurate documents)
Exogenous Factors	Weather Conditions Natural Disasters Crime
Endogenous Factors	Transport Mode Specific Failures (congestion, accidents, custom procedures in non-Schengen area)
Other Events	Demand Related (order cancellations, changes in the quantity, loading/delivery time as well as pick-up/unloading location of orders) Miscellaneous (failures in communication infrastructure, customer refusing acceptance of the goods)

Table 5: Sources and Characteristics of Unexpected Events [17], [19], [20],[21]

re-planning is an exhaustive procedure that could last for long, especially when a charter needs to be found (up to six hours). Even though it may not be optimal since many variables related to customer satisfaction, JdR's targets and LTL shippings complexity have to be taken into account. In addition, the organization and subsequently the planners do not have a clear picture of their actions, since they do not have visibility on the results, in terms of how profitable a plan was (mainly use activity based management). All these issues are escalated internally causing increased costs and unmet service levels (usually 80-85% when 90-95% was agreed with the customer) for JdR.

1.3 SCOPE OF THE RESEARCH

As already discussed above, planners at JdR face many challenges since they have to generate routes considering cost, service level,customer satisfaction and unexpected events, while they also have to handle a huge number of pulling (trucks) and pulled (trailers) units. In addition, they are responsible for assigning drivers to trucks and in the case of LTL shipping appropriately consolidate diverse type of commodities for multiple destinations in the most efficient way.

The research that was conducted on JdR was motivated from all the aforementioned aspects and its objective was the development of a mathematical model (OR model) and its solution algorithm for LTL shipping during offline planning. The target was the solution algorithm to provide planners near optimal suggestions when re-planning is necessary. Apparently, the model should consider the initial plan that was designed (offline planning) and the real-time information that planners receive during the execution process. The reference model of the study was the VAPCI [22] that was designed exclusively for JdR and currently takes only FTL into account. The research should extend the current model or design another VAP model in order to include the following characteristics:

- Reduction of fuel consumption (and consequently of emissions)
- Consolidation of shipments and
- Determination of cross-dock/ co- loading locations

The research took place in the International Transport group of JdR which is the biggest one and offers a wide array of daily scheduled LTL feeder services throughout Europe including an extensive network between airports.

It is worth mentioning at this point that the research is supported by EU's GET Service project. The goal of this project is to develop a Service Platform for Green European Transportation (GET Service) that will provide users with tools to make freight transportation in Europe more efficient and environmentally friendly. GET, taking into account all available information in real-time, should support stakeholders when deviations from the original plan exist by providing necessary information and offering alternative transport solutions. Subsequently, the platform could improve the way of dealing with unexpected events and lead to benefits for all involved stakeholders. The development of the novel transportation and route planning algorithms that use real-time aggregated information for green and efficient planning is one of the objectives of GET and an additional factor that motivates this research [17].

1.3.1 *Research Design*

Generally in JdR all the orders that do not fill a truck (which is usually 12,80 meters long) are classified as LTL, thus the loading meters of these kinds of shipments range from 0,1 to 14. As can be seen on Figure 6 during 2013 LTL shipping accounted for a significant percentage of JdR's total distribution operations with many of the shipments being below 2 loading meters. Subsequently, the extension of the VAPCI model or the designing of a new one, in order to consider aspects of LTL shipping is considered significant for the efficient as well as profitable use of assets. The development of a mathematical model and its solution algorithm, related to LTL shipping for re-planning the needed segment of JDR's network based on real time information, will facilitate the realization of both JdR's and GET service platform's objectives (which are supported by JdR as involved partner in the project). The first step for the development of such a model that can be applied on JdR's planning software (JPLEXS) is to define the main research question. After that the scope as well as the methodology that will be followed are determined.

[redacted]

Figure 6: Proportion of FTL and LTL shipping at JdR (2013)

Research Question

According to all the above aspects the main research question of this study is formulated as follows:

> *How does planning of LTL shipping, using real time data affect JdRs performance through the transportation network?*

As long as the focus of this research is on LTL shipping it is obvious that the consolidation of freight along with all the restrictions that accompanied it (commodity type, customer time windows etc.) constituted a large part of this study. In addition the extension of the VAPCI [22] algorithm in order to take into account reduction of fuel consumption, and consequent emissions was judged as significant during the design of the model. The determination of the cross-dock/ co-loading locations that have to be visited by the assets was also considered important along with decisions related to whether hiring of a charter is needed.

Scope

The research took place in the International Transport group of JdR which is the biggest one and offers a wide array of daily scheduled LTL feeder services throughout Europe including an extensive network between airports. Furthermore, no restrictions exist regarding the type of commodities (type of industries) that should be served and combined except from a distinction between hazardous and non-hazardous materials. As it has also been determined from the GET service platform three scenarios have to be considered:

- Real-Time Planning
- Optimal Resource Selection
- Executing Changes during Transportation

Since the initiation of this European project and through deliverables that have been published, various usage scenarios (road, train, intermodal transportation etc.) have been analyzed from the perspectives of clients, planners and operators, thus some limitations need already to be established. The scenarios that will be analyzed are referred exclusively to road transportation, since it is the most widespread mode of transportation and is related to the use of JdRs own assets (trucks and trailers), while the perspective is that of the planner (JdR). Possible events, which might occur during logistics or transport operations and could potentially lead to disruptions of the logistics chain, should also be considered in order to improve reliability of planning process (both offline and online). The most significant of these events is probably the freight shift, which was identified as one of the most severe problem for both offline and online planning.

Research Methodology

From all the aforementioned, it is obvious that diverse parameters had to be considered, thus a stepwise method is needed in order to cite all the stages and results of this study (Figure 7).

The remainder of this document is organized as follows: the next section includes a summarized version of the **literature review**, which had begun some months before this research took place. The specific chapter is divided into two main parts since the literature review included a research both in advanced tools and software, for estimating emissions produced by transportation and issues related to LTL shipping. The third chapter provides information about the results of the **performance analysis**. Specifically,transportation KPIs that are either identified on literature or indicated on

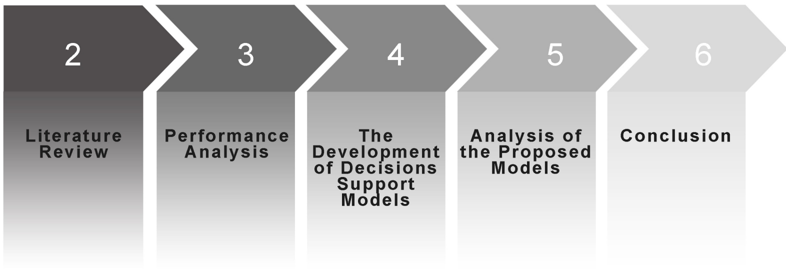


Figure 7: Overview of Research Methodology

the company are analysed. Data about the kilometres driving by the assets, the proportion of LTL shipping, the freight shift scenarios and many more were collected and analysed during the whole period of the research, in order to gain knowledge about the overall performance of JdR. In addition, main results and recommendations for potential areas of improvement are presented in order to determine aspects that the mathematical model can offer optimized decisions. Knowing the problems and identifying the appropriate literature judged as essential before the design of the mathematical model, thus the fourth chapter on this research includes information regarding **the development of decision support models**, which follows naturally. Transformations of the VAPCI [22] model are demonstrated along with its green extension in order to include reduction of fuel consumption, in addition to the design of the LTL-related algorithm. In the fifth chapter a detailed assessment of the algorithm is provided based on business cases that planners face in daily operations (**analysis of the proposed models**). Finally, the closing chapter of the study includes the **conclusion**, where the overall findings, recommendations, limitations and potential future areas of research are presented.

2

LITERATURE REVIEW

An extensive literature review, was conducted before and during the time the project took place, thus this chapter had been designed to give a theoretical foundation on the subjects relevant to this research. Specifically, this section has been divided into two main parts:

- Tools and Software for estimating emissions produced by transportation, and
- LTL shipping related literature.

Target of the first part is to present advanced tools and software that have been developed mainly in Europe and in the US for the calculation of emissions generated by road transport; while the second part provides firstly, a description of common transportation problems, such as the Vehicle Allocation Problem (VAP) and the Vehicle Routing Problem (VRP), as presented by Ghiani et al (2004)[33] followed by the review of LTL related literature. Considering the size of the material that was discovered, it was found significant to present a summarized version of the literature review, since an analytical description can be found on the papers that have been delivered for the partial fulfilment of the requirements for the degree of master of science in operations management and logistics.

2.1 CARBON EMISSION CALCULATORS

Transportation is a valuable and necessary part of modern society and its demand is closely linked with economic development. However, transportation is closely related to high levels of energy consumption and harmful environmental effects. Probably, the most detrimental of these effects is its contribution to the atmospheric pollution. Each litre of fuel that is burnt produces a variety of pollutants (carbon monoxide, volatile organic compounds etc.) that associated to some degree with air pollution problems, ranging from local direct health effects to global concerns such as the greenhouse effect. Target of the following part is to present advanced tools and software that have been developed mainly in Europe and in the US for the calculation of emissions generated by road transport.

2.1.1 *EcoTransIT*

Probably one of the most popular and user friendly online calculators is the EcoTransIT (Ecological Transport Information Tool) calculator. The project was motivated by five European railway companies in 2000 (DB Schenker Rail, Schweizerische Bundesbahnen (SBB), Green Cargo AB, Trenitalia S.p.A, Sociètè Nationale des Chemins de Fer Français (SNCF)) and subsequently new partners have joined (Red Nacional de los Ferrocarriles Españoles (RENFE) and Sociètè Nationale des Chemins de fer Belges (SNCB)). EcoTransIT identifies the environmental impacts of freight transportation in terms of direct energy consumption and in terms of produced emissions. It uses two methods of entering data, a standard and an extended one. For the standard method the user has to add details about the origin, the destination, the type and quantity of load, as well as the type of transportation used, to obtain information regarding the energy consumption and, the emissions of CO_2 and other pollutants. With the extended input method the user except from the above characteristics can also input the type of cargo (liquid, bulk or other), the extent to which ferries should be considered and the exact route that wants to follow (indicating locations from which the truck should pass). The tool additionally can produce graphs in which different transport modes that can be used for freight requests are compared. [25],[23].

2.1.2 *NTM*

NTM (Network for Transport and Environment) is a non-profit organization, initiated in 1993 with target to establish a generally accepted methodology to calculate environmental performance of various modes of transportation. Researchers on NTM created a calculator that allows buyers and sellers to evaluate the environmental impact of their transport activities. The input information that are needed by the calculator is: the transport mode, the shipment weight, the type of vehicle (diverse categories exist depending on the mode and fuel consumption), the load capacity utilisation, the distance (km), the fuel type and consumption, the emission factor, the energy content of the fuel, the use of filters or catalysts and the data for load capacity and default capacity utilisation. Using these parameters the methodology is able to produce results not only about the emissions of CO_2, but also of other pollutants (NO_X, HC, PM etc.). The method provides several average values and offers many assumptions, in the case that no actual data are available, since the target is the results to be seen as an indicators. The above occurs mainly, because fuel consumption and its consequential emissions are influenced by many parameters like weather conditions, driving style, vehicle maintenance, type of motor etc., so the precise estimation is quite complex. Thus, NTM offers default data for vehicles and load factors that cover a typical transportation in Europe [23],[24]. Obviously, various NTM documents have and will continue published in order to include the most up to date data.

2.1.3 *Artemis*

Artemis (Assessment and Reliability of Transport Emission Modelling and Inventory Systems) is a project initiated by the European Commission. As in the case of NTM, target of the project is to develop a commonly accepted technique of estimating emissions, by combining methodologies that have already been introduced with ongoing research. Using detailed data ARTEMIS can generate analytical results regarding national and international emissions. In particular, the project offers the following applications: classical emission inventories (at regional or national scale, per month or year), scenario calculation for assessing the impacts of alternative measures (time series over years), inputs for air quality models for assessing local and temporal impacts on the environment. The results include information regarding fuel consumption and emissions levels of regulated (CO, HC, NO_X, etc.) and non-regulated pollutants (methane, ammonia, benzene, toluene, etc.). Several traffic situations/scenarios have been shaped, by using different data regarding speed limits, traffic conditions and type of roads surface, for examining diverse types of vehicles and engines. Each of these traffic situations depicts realistic speed curves that have been recorded within several European research projects. Regarding the inputs of the model distance, fleet structure, type of fuel, age of vehicles, use of catalysts and/or filters [23], are some of the ones needed to produce results. Apparently, if many of these information are available, the methodology will be able to come up with more precise results [26],[27].

2.1.4 *EMISIA SA*

EMISIA SA is a spin-off company of the Aristotle University of Thessaloniki / Laboratory of Applied Thermodynamics, with target to provide environmental services, by developing software that facilitate international organizations to report emissions produced by transportation. The main products of EMISIA are: COPERT 4, COPERT Australia and SIBYL.

COPERT 4 is a software tool that is used for estimating air pollutants and greenhouse gas emissions from road transport worldwide. It offers a methodology, for collecting and reporting emission related data, that comply to the requirements of international protocols and legislation. The software offers data for 27 countries of Europe regarding vehicle population, annual vehicle mileage, vehicle speed, driving mode shares etc. for a time series from 2000 to 2030. The input data include activity data (fleet, mileage), usage data (speeds, shares), evaporation data (evaporation share, fuel RVP), temperatures and average daily trip distance. Except from the above, COPERT provides many more estimating options for calculating aspects like the beta of minimum and maximum temperatures or the relative humidity per month (%). In addition users are able to perform fleet configuration by selecting specific type of vehicles, fuel consumption, desired technology and many more. COPERT Australia is the result of a joint effort between EMISIA and the Queensland Department of Science, Information Technology, Innovation and the Arts (DSITIA). COPERT Australia serves the same purposes as COPERT but has been transformed to comply with the conditions in this continent. SIBYL, on the other hand, is a vehicle stock projection tool with cost related capabilities, that allows the formation and execution of target oriented scenarios. The user can assess diverse scenarios with real life data, fast and transparently enough, since a detailed vehicle stock baseline database has been developed for the 27 countries of EU. The software, in essence, offers an innovative and customized modelling framework in which several bottom-up scenarios can be evaluated [28].

2.1.5 *GREET*

GREET (The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model) has been developed in US and is a user friendly platform for evaluating the emissions associated to transportation activities. It allows the evaluation of various vehicle and fuel combinations on a full fuel-cycle/vehicle-cycle basis. GREET is equipped with a database, algorithms and a graphical user interface. Its first version was released in 1996 and, since then has been continuously updated and expanded in order to currently include estimations regarding: consumption of total energy (energy in non-renewable and renewable sources),fossil fuels (petroleum, natural gas, and coal together), petroleum, coal and natural gas, emissions of CO_2 and equivalent greenhouse gases (CH_4 and N_2O),sulfur oxides (SO_X), volatile organic compounds (VOCs), and many more. It includes more than 80 vehicle/fuel systems and covers various vehicle technologies. The results are presented as bar charts or pie charts (graphical interface) and organized into three categories: emissions, energy and general. [29].

2.1.6 *LEM*

LEM (Lifecycle Emissions Model) offers a number of formulas to the user which can be applied in Excel or other spreadsheet in order to estimate the energy use and the emissions for various pollutants. In essence is a quite detailed model that permits the estimation of lifecycle emissions and greenhouse gases produced by a variety of transportation modes taking into account the complete lifecycle of fuels, materials, vehicles, and infrastructure. Its main outputs include information regarding: the emissions per mile from motor vehicles, the emissions from electricity use and use of heating fuels, summaries of percent change in lifecycle g/mi emissions from alternative-fuel vehicles, relative to conventional gasoline LDVs or diesel HDVs and BTUs of process and end-use energy per mile of travel by stage of lifecycle, for different feedstock/fuel/vehicle combinations. It is worth mentioning that many data on energy use, fuel characteristics, and emissions are estimated or projected from 1970 to 2050. Although LEM has initially been developed in US, includes facts and figures for various countries and regions and in most cases information about specific commodities that produced in these countries [31].

2.1.7 *MEET*

MEET (Methodology for calculating transport Emissions and Energy Consumption) is another tool that has been developed in Europe for evaluating the impact of transportation on air pollution. Target of the project is to collect updated information regarding vehicles, making thus possible the estimation of emissions, which result from various transport modes. The program initiated by EEA and the main objective is not only to encourage but also to facilitate EU's governments to report annual air emissions inventory. The estimation of national emissions from road transport is available via the COPERT (section 2.1.4), but every country can report, using their own methods and models. As in the case of LEM the specific model presents formulas, that the user can apply in excel files to calculate the emissions from road transport. LEM included various sources but in the case of MEET the focus is mainly in transportation modes and except from the road encompasses rail, ship and air transport. In essence, it proposes a methodology for estimating emissions that generated by vehicles by offering a large amount of information on road transport. The methods that are used depend on the pollutant, the transport mode and the vehicle type. Specifically the methodologies that can be applied are generally categorized into: calculations based on transport activity, calculations based on energy consumption, carbon balance calculations and pollutant specific calculations [32].

2.1.8 *GHG Protocol*

The GHG (Greenhouse Gas Protocol) initiative launched in 1998 and is a US based non governmental organization with aim to develop for business a generally accepted methodology for estimating and reporting greenhouse gas (GHG) emissions. In order to become useful for different types of organizations and enhance transparency three different scopes have been defined. The first scope (Scope 1) accounts for the direct GHG emissions that occured from owned or controlled by the comapany sources; the second one (Scope 2) includes indirect GHG emissions generated by the consumed from the company electricity; while the last one (Scope 3) is appropriate for the calculation of other indirect GHG emissions(not owned or controlled by the company). The most common approach for calculating emissions is through the application of documented emission factors. However, since these data are hard to be monitored by the companies, accurate calculations can be obtained from fuel use and electricity consumption data. The tools include cross-sector methodologies as well as sector-specific tools, but are optional since the companies are allowed to use their own methods, if they can prove that are more accurate or are at least consistent with the standards that have been established by the GHG Protocol. In addition, guidelines are offered to companies for reporting the six greenhouse gases covered by the Kyoto Protocol carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6)[23][30].

All the aforementioned models have been created with different aims but common target to minimize emissions of pollutants.Most of them are really detailed since the generation of accurate results require a huge amount of input data. Close related features can be found in all the methodologies, but the selection of the most appropriate one depends on the objectives that each company pursue(calculation or reduction of emissions, amount of detail etc.). Table 6 provides an overview of all the tools that presented above.

Method	Scope	Level of Detail
EcoTransIT	Europe (excluding some countries)	Low
NTM	Europe	High
Artemis	Europe	High
Emisia SA (COPERT,SIBYL)	Europe, Australia	Medium
GREET	World, US focused	High
LEM	Various countries (US, Europe,Japan, Canada,etc.)	High
MEET	Europe	High
GHG Protocol	World, US focused	Medium

Table 6: Overview of Methodologies and Software for estimating emissions

2.2 LTL SHIPPING RELATED LITERATURE

The planning and managing of freight transportation comprises a significant portion of operations related literature. Mathematical models and heuristics have been proposed and analyzed from various authors, both from strategic and tactical level. The literature review that was conducted on LTL shipping present on its first part, some of the basic problems, as identified by Ghiani et al (2004)[33], while on its second part displayed a more detailed analysis of LTL related problems. More specifically, the following topics, authors and problem/models were identified:

2.2.1 *Common Transportation Problems*

Ghianni et all (2004)[33] presented the Vehicle Allocation Problem (VAP) which is the most common problem faced by FTL carriers. He modelled VAP as "a minimum-cost flow problem on a time-expanded directed graph" in which vertices represent origins and destinations and arcs are used to describe loaded, empty and inventory (idle) movements. The demand assumed to be deterministic, and only the case when a single vehicle type exists was examined. The planning horizon was known and assumed to be comprised by a finite number of time periods. The objective function, as it was formulated, corresponds to the total discounted profit over the planning horizon. The constraints ensured flow conservation and formation of loaded movements according to the demand.

Probably the most important and widespread combinatorial optimization problem, in the field of transportation, the Vehicle Routing Problem VRP), was presented also from the same author. The generation of efficient routes that have to be followed by a fleet of vehicles, for serving a set of customers is the target of the simple case as it was formulated by Ghiani et al (2004)[33]. He distinguished VRPs into two categories: Node Routing Problems (NRP) and Arc Routing Problems (ARP) and focus mainly on the first one of which many variations (VRP with Pickup and Delivery - VRPPD, VRP with Time Windows -VRPTD, Capacitated VRP CVRP etc.), were analyzed.

Another problem- challenge that is faced in particular by carriers, who are specialized in LTL shipping and presented by Ghiani et al (2004)[33]is the shipment consolidation and dispatching problem. The author described the problem from the perspective of a producer who has to decide the best way for delivering a set of orders to customers, over a planning period. Several issues, like the way that shipments have to be consolidated or the order that each stop is visited, have to be considered, and they constitute the main constraints in which the objective function is subject to. Time is a major concern for the generation of efficient load plans since deadlines have to be taken into account.

2.2.2 *LTL shipping relevant issues*

Selection of LTL Carriers

The distribution of goods from a destination terminal to local customers is a major issue for logistics managers, as they have to decide between using private trucks and hiring LTL carriers. Chu (2004)[7]developed a mathematical model (integer programming model) along with a heuristic algorithm for the truckload (private cars) and less-than-truckload problem, based on cost minimization. A comparison between these two models was presented to finally prove, that the heuristic algorithm could obtain optimal solutions (in terms of cost) in an efficient way (in terms of computational time needed for obtaining optimal solution). A mathematical model was firstly formulated by Chu [7] with constraints and assumptions that facilitate the structure and later analysis of the problem. The assumptions determined that there is only one warehouse system (destination terminal) from which all the trucks start and return, and the only operation that is happening is delivery. A customer is served by one vehicle (private or LTL carrier), and his demand should not exceed the capacity of the truck. The costs of operating the trucks are decomposed into fixed (personnel, insurance, etc.) and variable (fuel) costs. The heuristic algorithm that was described afterwards was called TL- LTL and was consisting mainly by three steps: selection, initial solution construction and refining procedure, taking into account a modification of the Clarke and Wright algorithm.

Management of Personnel

A major part of the total cost is derived from personnel costs, which include costs for drivers and employees responsible for sorting and handling loads. Consequently, LTL carriers except from other parameters should also consider the efficient management of personnel for minimizing these costs and achieve significant marginal profits. Erera, Karack and Savelsbergh (2007)[34] solely investigated the driver scheduling and load dispatching problem (DSLDP) from the perspective of LTL carriers. Specifically, they proposed a dynamic scheme for the management of linehaul drivers in a US LTL carrier. The best load dispatch times and driver-to-load assignments for some fixed- duration planning period have to be determined based on the renewable resources. The renewable resources in this case, were the drivers who have to be used for a limited time before resting (recharging). Furthermore, a trade-off between service and cost had to be taken into account. The scheme combined greedy search with partial enumeration and made use of real data. The periodic run of the methodology was judged as significant for using continuously available new data.

Except from the efficient trip generation that can be obtained for the drivers which leads to increased profits, many advantages can be obtained also from the right management of the personnel that is responsible for sorting and handling freight. Their job is labor-intensive and therefore costly, thus Bartholdi and Gue (2002)[35] focused on reducing labor costs in a LTL cross-docking terminal. Workers must unload, sort, and transfer a variety of loads from incoming to outgoing trailers. Their efficiency depends on how trailers are assigned to doors around the dock. Taking advantage of patterns of freight flow is an inexpensive way for achieving that. The paper presented models of travel cost and three types of congestion that are typically met in cross- docking terminals. These were used for the generation of layouts that minimize the labor cost. As the authors stressed, the layout for LTL terminals is similar in some ways to the problem of gate assignments in airports but differs in some aspects.

Load Planning

The load planning is another factor that has to be taken into account for optimized performance results. Katayama and Yurimoto (2002)[36] proposed a load planning model and a new algorithm along with a Lagrangian relaxation method in a study about LTL motor carriers. The problem took the name of load planning problem for LTL motor carriers and was formulated as a mixed integer optimization problem. An escalated approach was used for the formulation and its later solution, as first a pair of terminals with direct service had to be defined followed by the routing of freight over the network in these sets. In essence, a network has a tree- based structure were possible direct paths from an origin to a destination (terminals) can be identified and freights with the same destination should be loaded in a truck (the research doesnt explicitly state that this depends also from truck capacity and time windows). Direct services between these origin-destination pairs define the arcs of the overall network. For the formulation of the problem, satisfying service level and minimizing costs between two terminals were the two parameters that mainly had to be considered. Thus, the objective function was the minimization of the total linehaul cost. Specific rules for the operation of paths related to the fulfillment of a given service level were the constraints that the objective function was subject to.

With a similar procedure some years earlier Hoppe, Klampfl, McZeal and Rich (1998) [37], dealt with the strategic load planning (SLP) for LTL trucking. How to route consolidated loads directly in a tree-based structure was the main issue as before. The tree-based structure in this case was used to uniquely define the next terminal on a commodity's path. Given the current location of a commodity and its destination the next stop could easily be found. Each terminal had a specific handling capacity, while the number of trailers traveling along a route was restricted. The final goal was the minimization of the cost of sending trailers and handling freight. An algorithm consisting of a modified un-capacitated network design method and an add/drop procedure was used for this research. The solutions were found in a reasonable amount of time while the quality was judged satisfactory. A qualitative side was generated with an immediate comparison between current and historical load plans.

Van de Klundert and Otten (2010)[38], developed an analytical research for improving LTL truck load utilization on line. Models and algorithms for automated accept/reject decisions on transportation requests were explored for obtaining feasible, less costly solutions. They also stressed the need for collaboration among carriers, since large groups of them are more likely to achieve the desired results. Their paper focused on the improvement of truck capacity, as enabled by internet market places and mobile communication; where online freight marketplaces for spot markets (OFMS) were the main subject of it. The problem was formulated differently than a vehicle routing problem (VRP) since no routing decisions were involved. The acceptance of loads with pick up and drop off points along the route was the only optimization that was considered. The problem entitled LTL packing problem (LTLP) and the objective function was based on maximization of total revenue subject to truck load capacity constraints, while three different versions were examined: Classical/ off line LTLP, Online LTLP and On the line LTLP. The different versions of the problem allowed for useful insights. However, the requirements, which were needed, especially for the online and on the line LTLP, were out of the scope of the literature review, as they were closely related to computer science and information technology concepts.

Consolidation of Shipments- Collaboration

Two of the most salient subjects that were identified in LTL related literature were the consolidation of shipments as well as the collaboration between LTL carriers to achieve that. Although many researches have been designed, since the concept is an emerging trend it is still relatively unexplored.

Development and understanding of the economic mechanisms that rule freight consolidation can lead to increased profits and elevated levels of adoption for shippers and carriers. Arango and Ukkusuri (2013) [11] focused on this topic and described a recently studied mechanism for cost reduction, the so called combinatorial auction. Combinatorial auction is a reverse auction (auctioneers are buyers and bidders are sellers) that allows carriers to bid for bundles of lanes. Thus, the price of a shipment is determined as part of a bundle which is usually lower or equal to the price of serving a shipper individually. The whole procedure was beneficial both for the carriers who can serve various customers increasing their profits and for the shippers who can minimize their costs. The final decision is taken by the shipper who has to solve the Winner Determination Problem (WDP).

Dai and Chen (2009)[12] developed a mathematical model and a Lagrangian relaxation approach to construct a set of feasible vehicle tours and solve the collaborative logistics problem. The problem definition included multi-shippers and/or carriers. Each shipper before the collaboration served by one carrier and each carrier utilized an optimal transportation route. After collaboration both parties create an alliance with common delivery tasks and vehicle capacities. Objectives were the minimization of transportation cost and the design of a "fair cost and profit allocation mechanism" through a global optimal solution. Satisfying the delivery quantity of each product was the main constraint of this model. Shipping costs and quantities to be transferred from one node to another were displayed in two matrices for transparency before the model was formulated. The constructed mathematical model which was referred as collaborative logistics problem with LTL transportation (CLLTL) was compared with existing vehicle routing problems with pick-up and delivery (VRPPD) models before a Langarian relaxation was presented. The model operated more efficiently than VRPPD models as many aspects had been taken into account, while the cost savings that could be obtained with collaborative logistics seemed to be substantial. The Langarian relaxation was used to solve the mathematical model after a reformulation of it (by introducing integer variables.

Meier and Clausen(2013)[39], realizing that consolidation of shipments using depots/hubs is an essential parameter for cost efficient LTL networks, presented a cost optimal mathematical model for given average shipping volumes; considering transshipments and transportation costs. Because the real sized problems are hard to be solved by standard solvers, they proposed a combination of heuristics that produce a good solution, that can be used in CPLEX. The objective function consists of transportation and transshipment costs, while the constraints satisfy that each truck serves a specific route, (whether it is full or nearly empty) and the weight of the assigned to the truck shipments is not bigger than the capacity of the truck. Two different versions of the model were developed by the authors the MAPIT(multi allocation problem with integer trucks) which requires to transport unsplit goods from one depot to another, using two intermediate depots, and the IO-MAPIT which includes an additional constraint,that satisfies the circulation of the trucks.Meier and Clausen(2013)[39] examined the model by using real world data set for a big number of depots,that made heuristics necessary, since CPLEX completely fails otherwise.The experiments showed that the heuristics had a good strength for short and long running times while the raise of the lower bounds to get a better theoretical understanding of the problem judged mandatory.

Hernandez, Peeta and Kalafatas (2011)[10] proposed a deterministic and dynamic LTL carrier single carrier collaboration planning problem (DDSCCP) for small- to medium-sized LTL carriers. The problem was deterministic since the demand was considered fixed and dynamic because "the demand had time windows for load pickup/delivery, the collaborative capacities were time-dependent, and the actual holding costs encountered by a load depend on the number of intervals it was held at a transfer location (though the holding cost rate itself was fixed for a location)". From the former definition it could easily be understood that the time dimension was a key feature for the DDSCCP. Specifically, the route shipments over multiple originsdestinations increased the complexity of the problem, creating possible delays (mechanical breakdowns, congestion etc.), that cause in turn holding costs. Capacity acquisition and holding costs had to be considered for the development of collaborative routes and consequently operational plans. Thus, a time-dependent collaborative strategy had to be identified for the carrier of interest. This strategy should include a set of collaborative routes that minimize its total cost to service the corresponding demand. To ensure consistency with real-world cases, modelling of the latest entry and the earliest exit time widows were defined, while variable sets were determined to represent shipments entrance and exit in the collaborative network and the collaborative decision variables. Constraints were also formulated to guarantee the independent transshipment of shipments through the collaborative networks and to establish an upper bound on the available collaborative carrier capacity (in terms of volume). The objective function that was finally presented in the paper could be decomposed in two parts. One representing the collaborative capacity acquisition costs, and the other the holding costs at the facilities. It must be noted that the proposed DDSCCP formulation wass characterized by total unimodularity. Specifically, the problem was classified as a binary (01) multi-commodity minimum cost flow problem, enabling the circumvention of much slower integer programming solution algorithms (less expensive integer programming techniques). In the specific case, branch-and-cut algorithm was used for the problem to be solved in GAMS/ CPLEX.

Estimation of Market Rates

One of the most interesting papers that were found through literature reviews research was the one written by Ozkaya, Keskinocak, Joseph, and Weight (2010)[9]. The research proposed a model that generates better LTL market rate estimates, allowing carriers and shippers to identify cost savings opportunities. Specifically the authors developed a robust and analytical decision-support tool to estimate LTL market rates by combining quantitative data with qualitative market knowledge. The estimation of market rates was based on various factors such as geographic area, freight characteristics and relative market power of the shipper (or carrier). Shippers can use this model for identifying opportunities for cost savings and as a reference point for proposed new lanes. On the other side carriers pricing services can benefit from market rate estimates. The approach that was used decomposed the tangible and intangible factors that are responsible for different negotiating prices, while a multiple regression model that estimates the price for the shipments was formulated using both types of factors.

Author(s)	Topic	Mathematical Model	Heuristic	Software/ Methodology-Techniques
Hoppe, Klampfl, McZeal and Rich (1998)	Load Planning	✓	✓	pruning techniques, dual-ascent procedureCPLEX 5.0
Bartholdi and Gue (2002)	Management of personnel	✓	✓	Simulation (no further info)
Katayama and Yurimoto (2002)	Load Planning	✓		COMPAQ VISUAL FORTRAN Ver.6., Langarian relaxation
Chu (2004)	Selection of LTL carriers	✓	✓	Lindo 6.1, FORTRAN language
Erera, Karack, Savelsbergh (2007)	Management of personnel		✓	Greedy search with enumeration of time-feasible driver duties
Dai and Chen (2009)	Consolidation of Shipments-Collaboration	✓		CPLEX. Langarian relaxation
Van de Klundert and Otten (2010)	Load Planning	✓	✓	Various polynomial approximation algorithms
Ozkaya, Keskinocak, Joseph, and Weight (2010)	Estimation of market rates	✓	✓	Backward elimination strategy, regression-based methodology
Hernndez, Peeta, Kalafatas (2011)	Consolidation of Shipments-Collaboration	✓		Network simplex (NS) method,branch-and-cut algorithm,MATLAB,GAMS/CPLEX
Meier and Clausen (2013)	Consolidation of Shipments-Collaboration	✓	✓	CPLEX
Arango and Ukkusuri (2013)	Consolidation of Shipments-Collaboration	✓		Branch-and-bound algorithm (Java), CPLEX

Table 7: Overview of LTL related literature

Various models related to LTL shipping were discussed above. Each of them corresponds to different issues that are faced not only by shippers, but also by carriers. In addition, diverse methodologies and mathematical models were used/created following each author's method, thus the creation of a table with the main features of each article found significant. A chronological categorization, depending on when each article had been published, is used for Table 7 which provides an overview of all LTL related literature using a chronological categorization (depending on when each article had been published). The Author(s), the topic, the use of mathematical model and/or heuristics, as well as software/ methodologies- techniques are referred.

2.3 CHAPTER DISCUSSION

Target of this chapter was to establish a theoretical framework for the subjects relevant to this research. A body of literature with studies, methodologies and models had been identified and described facilitating the design of the decision support model. Since the aim of the research was twofold in the first part of this section the most appropriate tools for estimating emissions produced by transportation were analysed; while in the second one LTL shipping relevant issues were examined.

Gaining insights from both the performance analysis and the literature review, the time has come to move to the design of the tool, as long as we firstly define clearly the problem and decide which parts of the literature support the subject of this research. The following section will describe all the aforementioned in detail.

3

PERFORMANCE ANALYSIS

Data analysis is considered to be a significant process in gaining sufficient insights, discovering useful information and evaluating issues relevant to the field of research. Consequently, this chapter was designed to present all the results stemmed from the data analysis of JdR's performance indicators. Data regarding transportation KPIs are concentrated, investigated and analysed below, confirming (or disproving) existing results and, offering new perspectives on this research. However, the objective is not only to purely present these results, but also to identify areas in which the current research could be proved beneficial.

Furthermore, as it was already discussed in Chapter 1 re-planning is an exhaustive procedure with consequential operational and financial risks; thus this section explores the reasons behind that and identifies the extent of the problem. In the next section, freight shift scenarios are described followed by the evaluation of the current key performance indicators, that are used by the company (kilometres driven by assets, loading meters of shipments etc.) and the analysis of data related to the environmental performance of the company.

3.1 SHIFT SCENARIOS

From all the unexpected events that were shown on Table 5 (section 1.2.7), the ones that were identified at JdR as probably the most severe, in terms of frequency, are the demand related events. Examples of such kind of events include cancellations by the client or changes in the order of attributes like quantity, commodity code, as well as pick-up/unloading location on short notice. It is obvious that demand related events are also correlated with other unexpected events, like exogenous factors; for instance due to wintry conditions in an airport, the demand can shift to another airport leading to cancellation of previously reserved capacities and searching for new ones, that would satisfy this demand. In such cases planners have to adapt the transportation plan flexibly and quickly enough; and if JdR's own truck capacity is insufficient to cope with these changes, planners are responsible to find a charter to satisfy the demand.
In order to examine freight shift scenarios, hourly snapshots of JPLEXS were taken during a time period of one week, in a range of seven hours, between 9:00 and 16:00, and every 15 minutes between 16:00 and 17:00. The main results of the analysis are presented below.

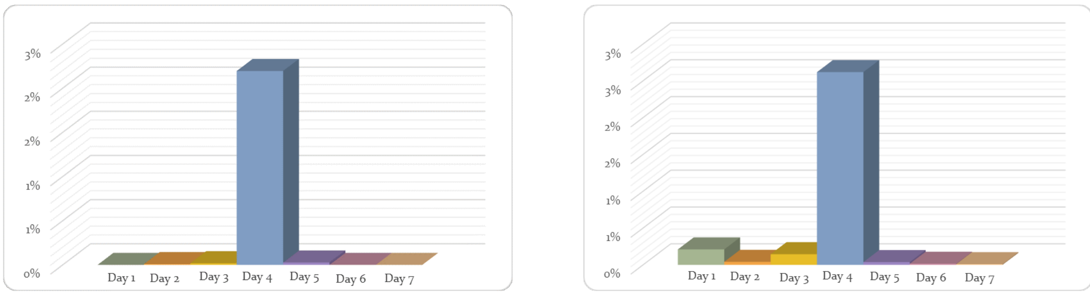
3.1.1 *Freight Shift*

The term freight shift corresponds to cases that occur when the originally planned pick up or/and drop off location of a freight request changes. Focusing mainly on air-freight, since the company offers competitive services in this industry, freight shift primarily happens because of the two following reasons:

- An aeroplane is rerouted to another airport (i.e., because of weather conditions, technical defects or a strike) and freight has to be picked up at that (different) airport.
- The airline changes the way in which it decides to load the aeroplanes due to efficiency in their own planning. As a consequence, different transportation orders are placed on different aeroplanes at different airports causing a shift in the freight demand towards JdR. This freight then needs to be dropped off at a different airport.

Generally, freight shift is associated to cases when a certain hub/terminal cannot be used, for any reason (that causes disruptions in an intermodal transport chain), and freight needs to be transshipped to another location in its route. When this location changes and the route of shipment has already being preplanned, a new planning has to be made.

The first type of freight shift is processed as follows: JdR receives a Freight Forwarding Manifest (FFM), which communicates the freight that will arrive on a given aeroplane and, that will be inserted into the chainware system. The FFM is sent when the aeroplane is ready to leave and is unlikely to be changed again. When the planner is satisfied, the order is sent to the JPLEXS system for asset planning. A freight shift occurs when the airline informs that the aeroplane will land at a different location, or when the airline sends an updated FFM indicating it. The second type of freight shift simply occurs upon request of the customer and is not based on an FFM. Compared to the first type, the second one is both entered and modified manually and not based on an FFM. The customer has to inform the planner about the event of a freight shift prior to the scheduled time of loading in order to enable an adaptation of the plan to meet the updated requirements.



(a) Shift on location of departure(reference on JPLEXS:from Location)

(b) Shift on location of arrival (reference on JPLEXS:to Location)

Figure 8: Average number of shipments presenting Freight Shift on location of departure and arrival, analysis of one week's data

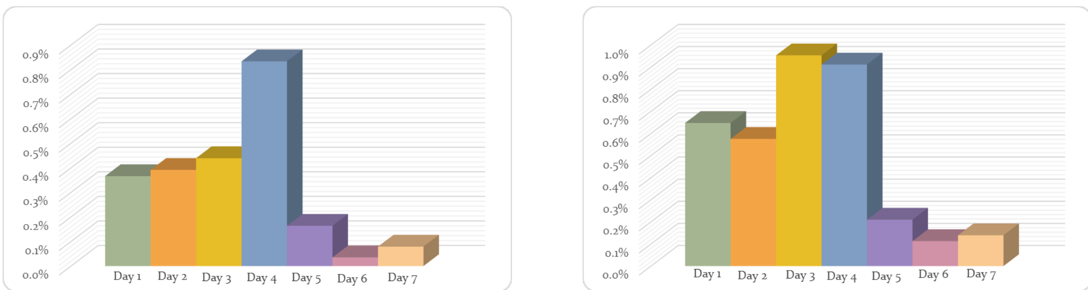
Using data that was sourced from JPLEXS and, having as reference the unique number that is assigned to each shipment, shifts on freight can be identified by examining if origin and destination locations remain the same or change each hour (or quarter). To estimate the percentage of shipments with shift on location, the number of shipments with shift was divided by the total number of shipments for each time interval (hour/ quarter) and these estimations were used to get the average number for each day. Figure 8 displays for each day the average number of shipments that had shifted to another location, and as can be observed, a change on the destination is more likely to happen (at least once per day), while the significant results of Day 4 are due to an airport strike in Germany.

It has to be noted that although the percentages shown in Figure 8 are not so significant, it is proved that freight shifts exist and that they lead to time-consuming re-planning of shipments and reallocation of assets. To address the case of shifted arrival locations, if no other optimized plan can be made, planners need to send empty trucks (empty running) to the new destination points increasing costs and fuel consumption (consequently also levels of CO_2e emitted). Obviously, when JdR's own assets are not available, for any reason (i.e., vehicle cannot be on time on the new destination point), planners are responsible to find a charter losing valuable time from other activities.

3.1.2 *Shift on Other Attributes*

As it was already discussed above, shift scenarios and specifically demand related events include, except from freight shifts, changes on other attributes of a shipment, like quantity. Using the same data that were collected to trace freight shifts (but different kind of information) changes on these attributes are investigated on the following part.

Loading meters are the first aspect that need to be examined. A loading meter is the standard measurement unit used by trucking companies and, corresponds to 1 meter of loading space of a truck's length. It was discovered that around 1-2% of the shipments every day presented shift on loading meters; the planners' response in such cases depends on the shifted quantity. If the loading meters of a transport order are increased there is a chance that this order will not fit in a single truck and, planners have to find a new truck or a charter to satisfy this request. Obviously, such an event complicates more the re-planning since in case there is additional loading meters the planning could change; it can happen that the planned shipment would have been loaded in a truck with shipments of other customers, but since the quantity increased the shifted order cannot be included in the planned truck. On the other side, if a significant reduction of loading meters happens planners need to reallocate shipments to trucks in order to fill them as much as possible (increasing utilization). As can be seen on Figure 9, the second case is happening more often than the first one, and although the shifts on loading meters are not more than 2%, it has to be noted that such kind of shifts cause a "butterfly effect", and thus planners have to adapt the transportation plan flexibly and quickly enough. In addition, except from shifts on loading meters changes can also be traced in other important aspects of a shipment related to its quantity/volume. More specifically, it was discovered that on average 1% of the shipments present shift on their *height*, while 0.7% of them every day present shift on their *weight*. Even if the two above aspects are not so important, since loading meters are the most basic indicator for a shipment at JdR, changes of these aspects provoke shifts of the loading meters. Changes on *commodity code* (type of commodity) are also possible but not so frequent (less than 0.5% and not every day). In such cases if the trailer is not appropriate a new one has to be found by the planners.

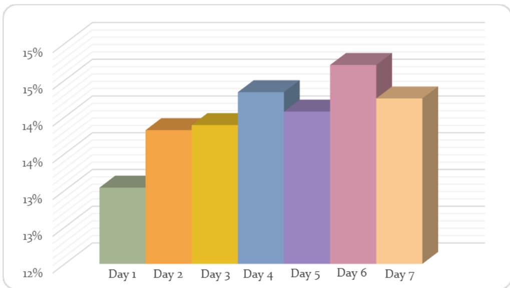


(a) Increase on Loading Meters (b) Decrease on Loading Meters

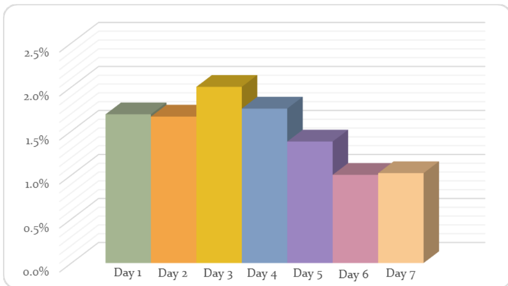
Figure 9: Average number of shipments that present shift on Loading Meters based on the analysis of one week's data

Charter is an important component of the operations of the company since in many cases JdR's own assets cannot be used. The percentage of shipments by which a charter needs to be used fluctuates between 13 and 15% with a 14% average for the week (Figure 10,(a)). Besides that, it was pointed out that a planner, for any reason may have to shift the delivery of a shipment *from owned vehicle to charter*, but how often can this happen? During the investigation of freight shift scenarios this feature was also taken into account and it was proved that 1.50-2% of the shipments exhibited shift from owned to charter (Figure 10, (b)), while 0.7% of the shipments presented shift from one charter to another.

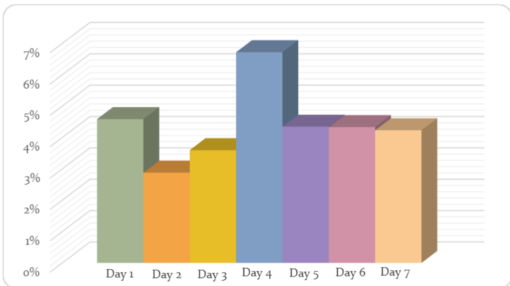
Under the freight shift scenarios two more aspects were examined: the shift on *distance* and *truck number*. Shifts on distance are directly related to freight shift scenarios (section 3.1.1), which lead to increase or decrease of the associated travelling distance. According to the analysis of this aspect on average 4.3% of the shipments presented shift on the distance with the percentages for each day varying from 4 to 6% (Figure 10,(c)). Changes on the truck number happen when a different truck has to be used instead of the one that was initially planned. In general, planning happens three to four hours before execution, thus planners have some time to adapt a transport plan and increase utilization of assets. If more shipments can be loaded into a truck, avoiding movements of semi filled trucks, a reassignment of shipments to trucks can happen leading to changes on truck number. In addition, such kind of shifts can also be linked to delays due maintenance of a truck or more rarely to changes in the commodity code (due to human error), since a new trailer has to be found and restrictions exist on the assignment of trailer to truck. As it was estimated 4 to 7% of shipments each day displayed such kind of shift (Figure 10,(d)).



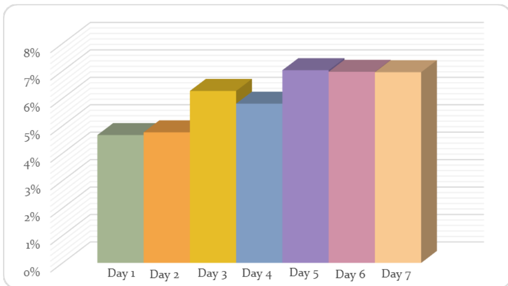
(a) Percentage of Shipments that use Charter



(b) Shift from owned to charter



(c) Shift on Distance



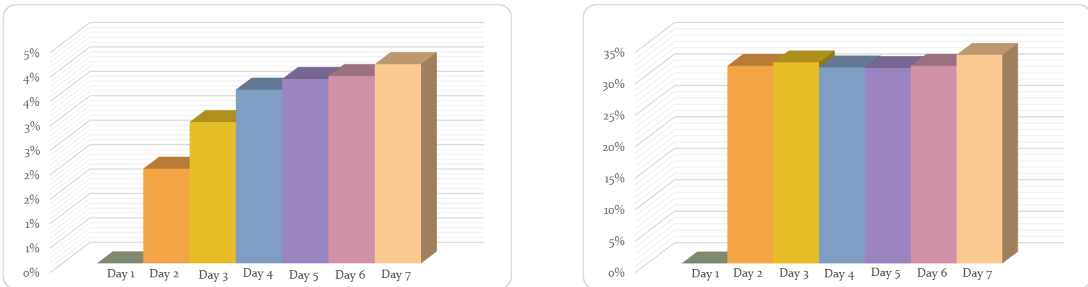
(d) Shift on the Number of Truck Used

Figure 10: Use of charter, shift from owned to charter,shift on distance and truck number

3.1.3 *Other Results that sourced from Freight Shift Scenarios*

JPLEXS is a really powerful tool and much information can be sourced to assess various aspects on JdR. Since a large amount of information were available during the examination of freight shift scenarios, it was also found significant to investigate the *split on shipment routes* and the percentages of *shipment updates* in fixed time intervals.

A transport order may be too large to fit in one truck, thus multiple shipments can be created. Such shipments have the same booking number but different and unique shipment numbers. For planning optimization reasons these shipment numbers could also be split in turn into two or more routes. These routes are called *shipment route numbers* and can be recognised by a letter next to the shipment number (i.e. 160518438a). As it was estimated on average 3% of the shipments presented split of shipment routes with the daily results fluctuating from 1 to 4% (Figure 11, (a)). Obviously, the case of freight shift was also taken into consideration, but the percentage of changes on split shipment routes was not so significant since on average less than 1% of them showed such changes (both for origin and destination location). The number of shipments *update*, on the other hand, was proved to be an important element in this research, since information regarding the planning quality can be sourced. During the first days at the company questionnaires were distributed to planners to assess the quality of planning. According to these results, which are mainly based on planners' experience, around 50% of FTL and 70% of LTL shipments needed re-planning. Consequently, planners who approximately plan 75 to 150 shipments in a working day have to re-plan almost half of them. Using the data that was sourced from JPLEXS and the incoming shipment message, it was possible to identify in practice how many of the shipments were re-planned. Each time that a shipment had been re-planned a message appeared in the screen indicating "Update". According to the estimation that was done it was found that almost 30% of the shipments in a week needed re-planning with the values between the time intervals fluctuating between 30 and 35% (Figure 11, right). Using these estimations and the results obtained from the questionnaires, it can be concluded that around 30-50% of the shipments needed re-planning in a working day.



(a) Split of Shipment Routes

(b) Shipment Updates

Figure 11: Percentage of split shipment routes and shipment updates

3.2 ANALYSIS OF PERFORMANCE INDICATORS

The previous section was designed to solely investigate shift scenarios and aspects that were sourced from these data, while the whole analysis was based on data that were collected by JPLEXS, during a week. Beside that, it was also found significant to examine the current performance indicators used by the company for a bigger interval of time (months), in order to gain sufficient knowledge before the conclusions of this chapter are drawn in the discussion part. The targets of the company have already been specified in the section 1.2.5, so the objective of this part is to investigate which and to what extent each of them are fulfilled. Since the data on this subsection concern a larger time period, Microsoft Excel [40] along with IBM SPSS Statistics [41] were used for the analysis of all the following aspects in the subsections. As was also done in the previous section, this part will also investigate the reasons behind re-planning and, it will identify links with the indicators that are used by the company.

3.2.1 *Loading Meters*

Loading meters is one of the most important KPIs used by JdR. As it has already been discussed, loading meters are the standard measurement for trucking companies, and planners in JdR are responsible for designing the most efficient plans for the assets of the company in terms of utilization. The target of the company is 80% use of loading meters per vehicle (load factor, loading meters) and this is what this subsection investigates. It also has to be noted that from the following analysis empty running (which corresponds to zero loading meters) have been excluded and, the focus is solely directed towards the quantities that are above zero, since empty running may not only happen in cases in which a demand has to be satisfied. Movements of the vehicles within a small geographical region (i.e., for maintenance) or the use of vehicles exclusively for operations inside the terminals are also included in empty running, but they are not recorded explicitly on JPLEXS.

Figure 29 in Appendix A shows, in two randomly selected months (April and June 2014), how the loading meters are fluctuated. From just a rough observation of the two figures, it can be seen that mainly loading meters range between 12 and 14, while smaller numbers (gaps in the figure) are also visible. The same analysis took place for the six first months of 2014 and the results for each month were compared and analysed. As can be seen on Figure 12 the percentage of shipments in which the truck is loaded less than 80% is really significant, generating margins of improvement. Generally, if also empty running was taken into account, utilization of assets would have fall more, but it should be noted that although the target does not met a pattern analysis can show that most of the assets are close to it and some of them are exceeding. In addition, there are also cases in which a customer asks for exclusive service, meaning that is willing to pay for a full truck although the shipment is LTL. Such cases are happening often but are not registered on JPLEXS, thus an additional analysis of cost versus revenues from each activity will be needed to reveal such situations. Obviously, service levels in the last case are increased while utilization of assets are diminished.

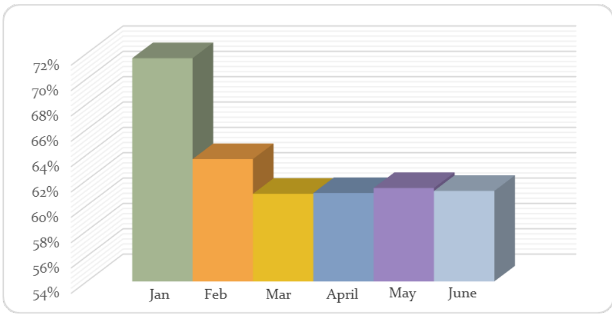


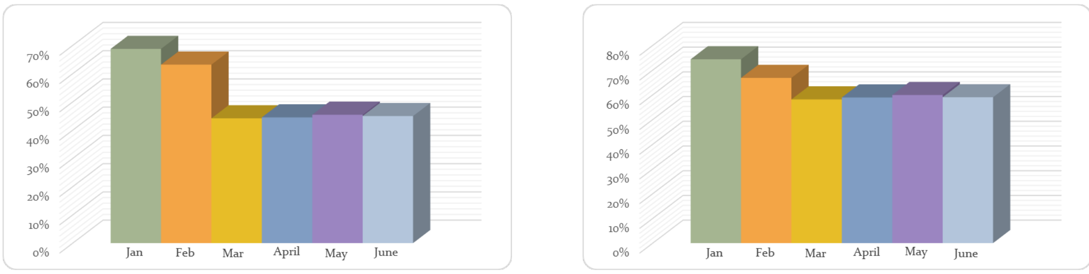
Figure 12: Percentage of Shipments that truck is less than 80% loaded

3.2.2 *Time Windows*

On time performance, according to the specifications that are given by the customers, is another important performance indicator for the company, and it is directly associated with increased service levels and customer satisfaction. Both loading and unloading *time windows* are analysed below; the unloading time windows are more strict compared to the loading ones, since they are defined by the customers and associated to their satisfaction. For the loading time windows planners have more flexibility in defining the departure times since they can estimate the amount of time needed to reach the unloading and, a better load and transportation plan can be designed. Obviously this does not apply to all the shipments and, for some special attention is needed since the time windows are more strict.

Using data from JPLEXS is easy to examine the time windows since a large amount of information is provided including earliest, latest and actual start and end for both loading and unloading times. Figure 13 presents the percentage of shipments for a six month period that satisfy time windows on loading and unloading. Probably the most obvious observation that can be extracted from this figure, is that the percentage of shipments with satisfied time windows on unloading exceeds the ones on loading. Such results also confirm the previous statement, since the percentage of shipments with satisfied time windows on unloading times in some cases is more than 10%. Further, the average number of shipments with satisfied time windows on unloading during the first six months of 2014 is

63% with the percentage of loading to be slightly more than 50%. Consequently, almost half of the shipments do not satisfy loading time windows, while the number of the unloading is lower than that.



(a) Percentage of Shipments with Satisfied Time Windows on Loading

(b) Percentage of Shipments with Satisfied Time Windows on Unloading

Figure 13: Percentage of shipments with satisfied time windows for loading and unloading for the first 6 months of 2014

In any case, it was found also significant to investigate on how the delay is distributed and, the mean delay of the shipments behaves. For this reason a histogram was created for the month March using the data only for unloading which, as proved, is the most significant. Figure 14 demonstrates the frequency of delay in about 7527 shipments which present a mean delay of about 9 hours. The above results give space for improvement, and are especially significant for the design of a decision support tool for LTL, since many shipments with strict and more relaxed time windows have to be combined in the vehicles, for increasing utilization and customer satisfaction.

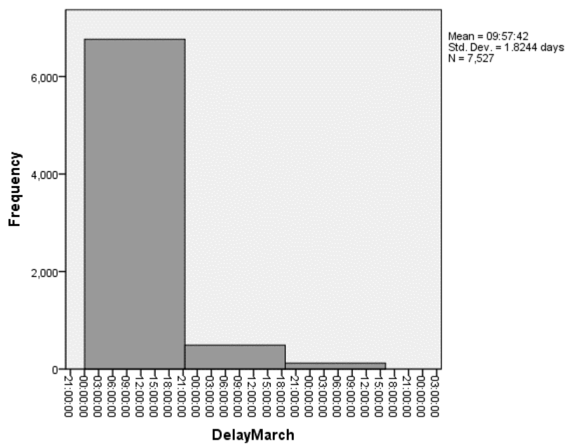
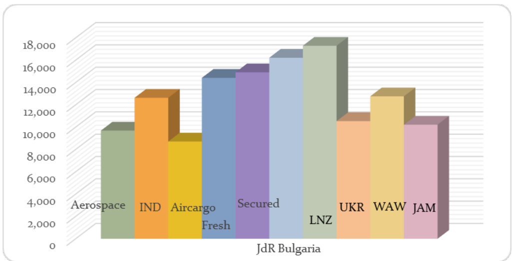


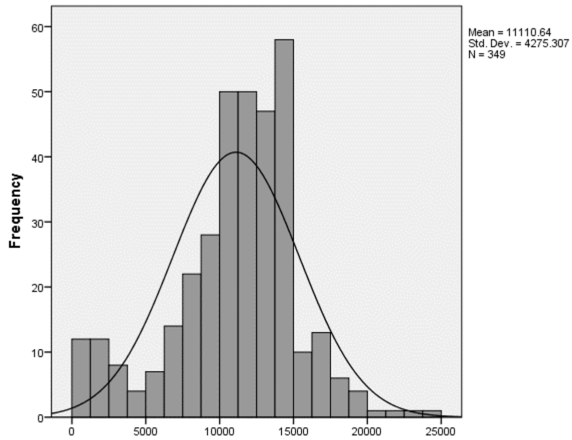
Figure 14: Mean unloading delay for 7527 freight requests during March 2014

3.2.3 *Kilometres (km) driven*

Since *kilometres driven* by assets are one of the most important performance indicators for the company, it has been established the target to achieve more than 10.000 km per month per driving unit. Undoubtedly, though, the kilometres driven by assets depend on the number of freight requests per month and on the way that planners position the assets. The data of each month per asset and planning group are recorded analysed and presented to offer valuable informations. It has to be noted that analysts in the company use an extrapolation method, based on historic data and weighted averages, in order to obtain results as accurate as possible. It should be also noted that the analysts are working in cooperation with Trimble, a company that collects information from the onboard computer and offers tools for managing these real time data. Thus, information can be sourced regarding the kilometres driven per day and per assets and the total kilometres per month. As it is illustrated on Figure 15, (a) almost all of the planning groups in the company achieved the target for the first semester of 2014 while the rest is close enough to it. In addition, the average kilometres per vehicle for the first six months of 2014 estimated and, the histogram on Figure 15 (b) demonstrates these numbers for a sample of 349 vehicles with a mean of 11.110 km driven. As it can be seen a theoretical normal distribution curve has been added showing that near the mean and right of the curve the values resemble the normal distribution, while in the left edge the values are higher. Further analysis on the results also proved that almost 70% of the assets are above the target that has been established.



(a) Average Kilometres driven per planning department (first six months of 2014)



(b) Histogram and normal curve for average kilometres driven by assets (first semester 2014)

Figure 15: Average kilometres driven per planning department and histogram for average kilometres driven by assets (first six months of 2014)

3.2.4 *Empty Running*

Throughout this paper it has already been mentioned that planners in the company may arrive at the decision to use an empty truck since no assets are available in the location of demand, leading to *empty running* of assets and increased costs for the company. This specific aspect was also object of Raoufi's [22] research, since one of his targets was the minimization of empty running and the resulting associated penalty costs. Poor decision making regarding positioning of the trucks and lack of future visibility regarding the demand needs per location in the network can also be blamed on these empty running operations. It is worth mentioning, though, that empty running is also associated with other activities like mounting and maintenance of the vehicles, as well as use of vehicles and/or trailers exclusively for operations inside terminals. Thus, an attempt was made to exclude data related to these activities from the following analysis.

The method that is usually applied in the company for estimating percentage of empty running per asset is the ratio of kilometres running empty to the total kilometres driven per week. Using the above method and data for 14 weeks, it was estimated that on average 20% of the miles that the assets are doing in this time interval, was empty running, with an average of 371 km per vehicle. To further examine this aspect a histogram was created showing the distribution of empty running in the fixed time interval. As it is depicted in Figure 16 most of the assets present less than 400 km of empty running per week with a mean of 379 km per asset. It has to be noted that the high

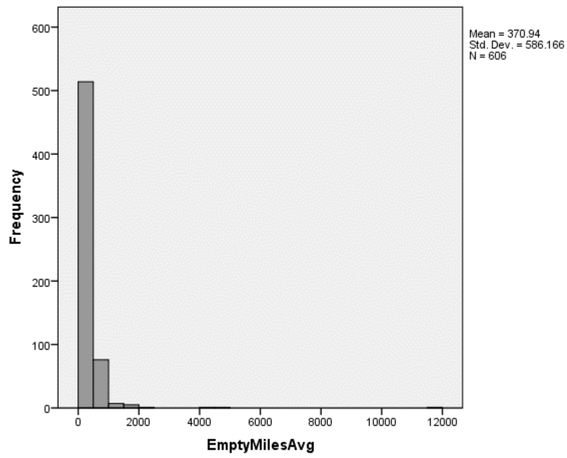


Figure 16: Average Empty Miles for a time interval of 14 weeks and a mean of 370 kilometres

numbers retrieved are caused by ad hoc charters, which were not possible to be completely excluded from the data analysis.

At this point it can also be mentioned that empty running of trucks is also associated with increased levels of emissions. Even if the proportion is lower in comparison to a full truck, this effect cannot totally be ignored, since generally speaking is also a reason for pushing up fuel prices. Therefore, better handling of the fleet and efficient operation can both lead to sufficient cost savings and environmental benefits.

3.2.5 *Delay Reasons*

Planners face many challenges each day and a lot of unexpected events can happen before and during the execution of a transportation plan, leading to delay of shipments. Obviously, such events are associated with re-planning and, planners are also responsible for the smooth compliance of an order, based on real time data that can be sourced from the BCs, which are installed in each vehicle. Not always, but in most cases these *delay reasons* are recorded on JPLEXS and thus, it is possible to identify the most common one.

As it is displayed on Figure 17 long loading (22%), ferry/shuttle delay (14%), traffic problems (13%) and co-loading shipments for different customers in a vehicle (10%) are the most significant reasons of delay. On one hand traffic and ferry/ shuttle delay can be described as random events and, are not predictable, as they depend also on other factors (i.e. weather conditions, accident); on the other hand long loading and co-load can be predicted and are the consequence of poor planning. Co-loading reason mainly occurs because planners are able to make a better combination of asset and freights, when a better opportunity (new freight request) comes up. The algorithm that needs to be created has to take into account the co-loading since consolidation of shipments will constitute a main feature of it, offering more flexibility during the decision making. Long loading is caused mainly due to busy gates at the hubs, which is an aspect that can also be controlled using historic data and demand characteristics for each location. From the delay reasons that are below 10%, "Other Due JDR" reason cannot be ignored, since as it was discovered, it corresponds directly to poor quality of planning, and about 7% of the shipments presents this reason of delay.

Another event that was found significant is late report of loading with a percentage of 11%. Usually this is happening when the driver is not informed of the loading location. In such cases

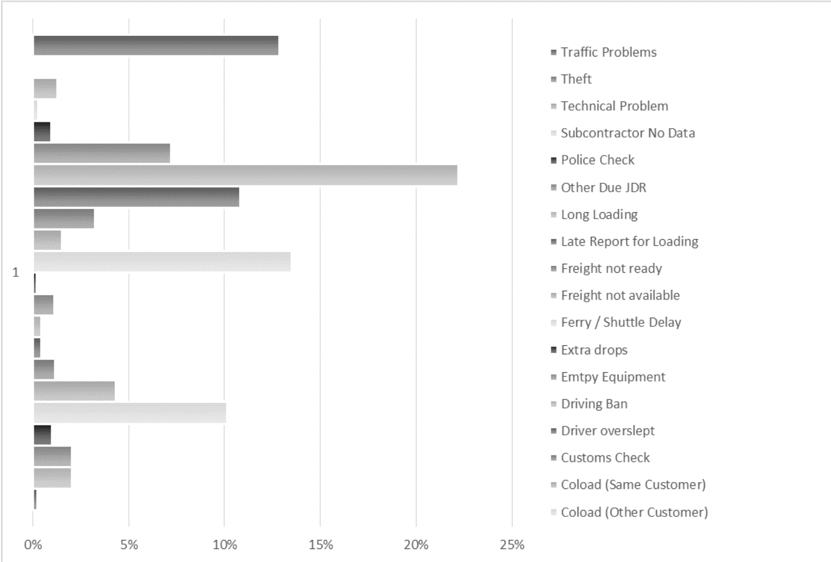


Figure 17: Percentage of occurring delay reasons for the first semester of 2014

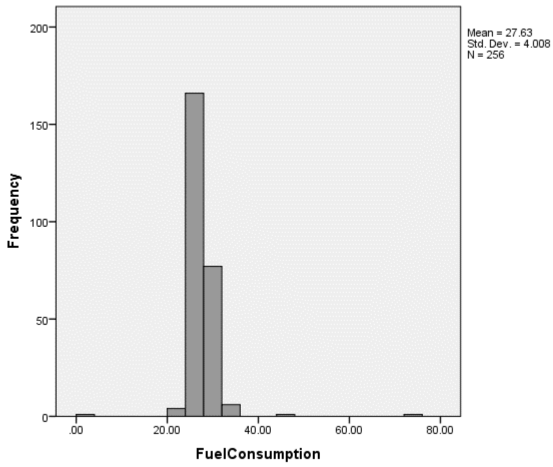
increased communication between planners and drivers can eliminate such a delay event. It should be mentioned that delays caused by unavailability of information regarding charter keep a really small percentage (0.2%), proving that a relatively quick assignment of an order to charter is possible.

It should be stated that the specific analysis cannot be used for drawing results regarding the percentage of shipments that present a delay, since in many cases the reasons are not recorded by the planners, who simultaneously have to arrange other activities online. More efficient planning and better communication and cooperation with drivers and customers may decrease the percentage of unexpected events that can be controlled. In other cases, like bad weather conditions or technical problems, experience and quick reflexes of planners can help them to adapt the transportation plan flexibly and quickly enough.

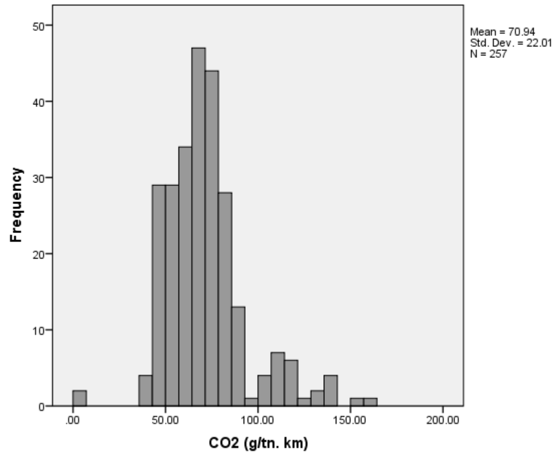
3.3 ANALYSIS OF GREEN INDICATORS

As it has already been discussed in the introduction part of this paper (section 1.1), the trucking industry is one of the major contributors to greenhouse gas emissions, thus attempts are made both from governmental institutions and companies to reduce the environmental burden. Transportation domain accounts for a significant share of the global CO_2 emissions, containing emissions that derive from the combustion of fuel for all transport activities and, it is the second most contributing domain after energy in Europe [4], [42], [43].

JdR does not deviate from this trend and actively makes attempts towards sustainable mobility, by participating in projects that directly or indirectly promote the aforementioned target (GET service, lean and green), estimating fuel consumption and CO_2 emissions of the assets, as well as transforming, acquiring and operating more sustainable vehicles (EUR-5 and EUR-6). Since one of the targets of the present project is to also to extend the VAPCI algorithm [22], considering minimization of fuel consumption and consequent CO_2 emissions, it was found interesting to investigate the environmental performance of the company using the two above aspects (fuel consumption and CO_2 emissions generated by the assets).



(a) Average Fuel Consumption of assets



(b) Average CO_2 (g/tn. km) emitted

Figure 18: Average Fuel Consumption and CO_2 emitted by assets for a period of four months

The company, in cooperation with Shell, collects and analyses data regarding the fuel consumption and CO_2 emissions of each week and for all the assets of the company, offering useful information and insights. It should be noted that weighted average values are used for each asset, which is an appropriate method if one considers that fuel consumption is not so easily to be estimated, since it depends on many factors like driving behaviour, outside temperature, truck load, type of engine, etc. Data for a time period of four months were collected for the current research and the results are examined below. Using the weighted averages of each week (which have already been estimated by the company and Shell) the average prices of fuel consumption and CO_2 emissions for each asset were estimated and, histograms were created to examine the frequency of these values, during the four months. Obviously the utilization of an asset during a week was taken into account, thus the weeks that have no data for specific assets were excluded. As it is illustrated in the Figure 18, fuel consumption present a mean of 27.63 litre per 100 kilometres in a sample of 256 vehicles and an average of 27.5 litre per 100 kilometres. The CO_2 emissions, on the other hand, have a mean of 70.94 grams per ton kilometres, that comply with EU standards [44].

Since the data that were sourced to examine the environmental performance of the company offer a variety of information, it was found interesting to also identify what are the response of each planning department and if there are deviations between them. As it can be observed from Figure 19 "fresh" and "industrial" have the highest levels of fuel consumption, since the first one is associated to the use of cooler trailers, which are linked to high levels of energy consumption, while the latter one is related to the transportation of relatively heavy freight. "Secured" are the ones with the lowest levels of fuel consumption since lightweight freights are usually assigned to them, like tobacco. Generally, the average prices (weighted) for all planning groups fluctuate between 26 and 28 litre of fuel consumption per 100 km with an average of 27.28 for a time period of four months. Regarding the CO_2 emissions all the planning groups maintain average values between 62 and 74 gram per ton km with airfreight and aerospace to be the most contributing groups. It should be noted that the categorization of planning groups on the following figure is slightly different than the one on Figure 15, because starting from May 2014 a different division of the company was used for reasons of efficiency and accuracy regarding the obtention results.

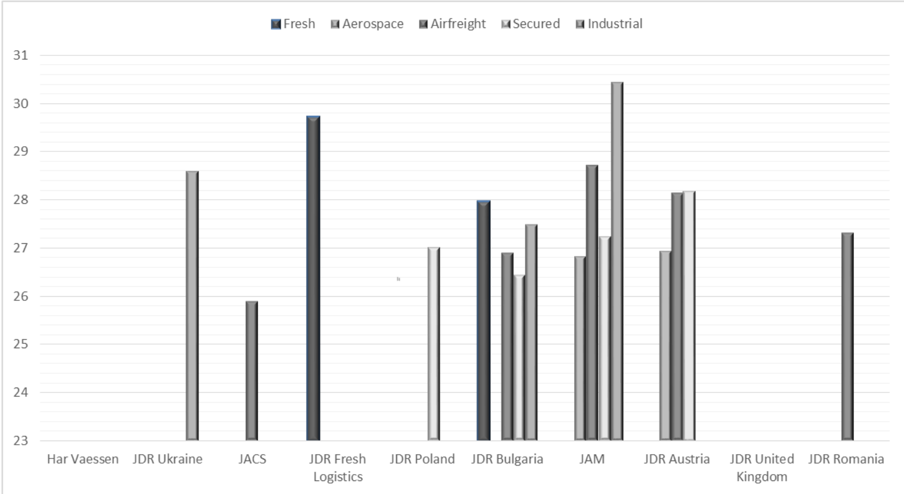


Figure 19: Fuel Consumption (sum of litre per 100 km) per planning group and business unit for a period of four months

3.4 CHAPTER DISCUSSION

Throughout this chapter a detailed analysis was made on shift scenarios, as well as on key performance and environmental indicators of the company, based on data that was sourced from JPLEXS and, in some cases preliminary examined by the analysts of the company.

Although the results from the freight shift scenarios did not seem to be significant, this aspect can not be ignored, since it is also associated with shifts on other attributes, like distance and truck number, and apparently with the procedure of re-planning. At this point it should be reminded that in order to examine these scenarios data, of only one week was used, thus further examination is needed. However, it was already proved that for instance when a strike took place on a day (Day 4, Figure 8) the percentages increased considerably. The shifts that were noticed on loading meters are an issue, that a tool designed to support decisions related to consolidation of shipments over a time period, can take care of. Thus, planners will be able to have an alternative and faster solution when changes and consequent reallocation of shipments to assets should happen.

Considering the analysis of key performance indicators for the company, it was proved that some of them satisfy the targets that have been established by the company, while others slightly deviated. In general, the aforementioned indicators can be divided into two main categories: operational and quality of service indicators. Regarding operational indicators, it was confirmed that kilometres driven by the assets and empty running comply with the standards that have been established by the company, while the aim of achieving 80% use of loading meters per vehicle is lower than the desired company results; even if the aforementioned indicators are also related to the cost and revenues that the company has from each transportation order. Many factors need to be taken into account in order to estimate precisely the trade-off between profit and cost, and it has to be highlighted that also planners do not have a clear picture of their actions (in terms of cost and revenues). On the other hand, satisfaction of time windows is a measure of quality service and, as it was proved in general, they are fulfilled; though, some of them deviate from the intervals, especially during the loading of shipments. Time windows is an aspect that a decision tool can offer high quality suggestions in addition to better decisions regarding the loading/ utilization of assets. Considering delay reasons, it seems that many of the factors that cause re-planning could be controlled with better communication and prediction of expected demand, while others are more uncertain and, in that case the experience of planners seems vital.

Regarding environmental performance of the company, the results showed a homogeneity on fuel consumption for the fleet of vehicles used by JdR, while the emissions of CO_2 fluctuated more, depending on the type of trailer used. Empty running can also be blamed for some of them, thus better decisions regarding positioning seems to be essential. The research that was conducted by R.Raoufi [22] included such kind of decisions based on costs, without taking into account fuel consumption of assets. Consequently, the design of a support algorithm that generates decisions based both on costs and fuel consumption of assets, can offer substantial benefits.

Evaluating the aforementioned section and considering the complexity and variety of issues related to LTL shipping, it seems that the development of a tool supporting such kind of decisions can have a positive effect on JdR's performance. In particular, an algorithm that supports decisions related to consolidation of shipments, should be a primary issue of this research, since significant results can be obtained regarding costs, utilization of assets and quality of service. Simultaneously, the extension of the current VAPCI [22] for considering fuel consumption on both loaded and empty vehicles can be proved to be a useful tool, especially in decisions related to the positioning of the assets.

4

THE DEVELOPMENT OF DECISION SUPPORT MODELS

After establishing a theoretical foundation with the literature review part (section 2) and, obtaining useful information and insights about the company, its operations and performance from Chapters 1 and 3, this chapter is dedicated to the design of the decision support tools. The objective of the present research is the development of a mathematical model (OR model) and, its solution algorithm that will offer high quality alternative decisions to the planners (during offline planning) considering reduction of costs and increased service levels. Although the initial target of the project was to focus solely on LTL shipping, it was found significant to extend the current VAPCI model [22], which is planned to be implemented at JdR, in order to take into account fuel consumption and reduction of CO_2 emissions. However, during the implementation of the VAPCI model [22] infeasible results were generated and, its transformation was judged imperative. Consequently, two models will be presented in this chapter, specifically:

- The transformed and extended VAPCI model [22] that considers only FTL
- A decision support model for LTL shipping, considering mainly consolidation of shipments and charter assignment.

Thus, a stepwise method needs to be used in order to describe in detail both models. Firstly, the decision to create the two algorithms based on costs instead of revenues will be explained, followed by the description of the transformed VAPCI model (indicating deviations from the original one). All the extensions of the model regarding charter decisions and heterogeneity will be explained in the subsections of the same part. An analysis of the model that was created for LTL follows, where all the reasons behind the decisions that were taken during the design process will be clarified, along with the extensions that were implemented. The contribution of both models to the general research will be analysed at the discussion part of this chapter.

4.1 COST VS REVENUE ALGORITHM

Costs and revenues are the two main aspects used by companies to assess the success of their businesses. Thus, as it was already discussed in Chapter 2, many algorithms have been created based on these two features. Many of them are cost driven and others revenue based algorithms, while there are also some based on profit. However, the total profit of a company is more volatile, depending on many factors, and such approach was soon judged inappropriate for this case.

Apparently the algorithms that will be discussed in the following parts need to be based on either profits or costs to support high quality decisions for the planners. Raufi [22] designed a cost based algorithm and, the main issue during the first days of implementation was whether that was the correct approach. Revenues on trucking companies fluctuate more than costs, and as it has already been discussed, they depend also on the service level that customers demand. Hence, the market is characterized by a low degree of transparency which makes revenues harder to be controlled.

For instance, if exclusive service is asked from a customer, this will offer more revenues than if no specific requirements have been determined. Costs, on the other hand, although they get revised periodically, are more stable, and specific information regarding the cost per activity and planning group are used by the company. In particular, the company has detailed information regarding the costs of all the activities that can take place (loading/ unloading, mounting/ dismounting, positioning etc.) by establishing tariffs and including all the various costs that apply (fuel, personnel, etc.), as well as the overhead expenses related to the use of assets. So it should be clear that the decision support models should be based on costs instead of revenues, in order for the planners to have a coherent picture of their actions, in terms of cost.

4.2 VAPCI

The reference model used for this study is the model that had been created by Raoufi [22], which in turn is based on the "Vehicle Allocation Problem" (VAP) model, that was introduced by Ghiani [33]. In the coming subsection the revised VAP, based on costs, will be introduced followed by the description of the various extensions that were implemented in the model. In addition, all the transformations that have been applied to the initial model [22] are indicated and explained in detail throughout the following sections. The main *assumptions* of the model are:

- The terms truck and trailer are used interchangeably, since truck and trailer are consider together (JPLEXS already supports assignment of trailer to truck).
- All demands are non-stochastic and each of them corresponds to one full truck.
- Service time (loading/ unloading) in each location is equal to zero.
- Travel time between two locations is proportional to distance and known in advance.

4.2.1 *VAP basic model*

Vehicle allocation problems are faced by carriers that generate revenue by transporting full loads over long distances. When the vehicles owned by the carriers deliver a load, these vehicles need to be repositioned to the pick up point of another load or to another location in anticipation of future demand [33]. However, as it was discussed above from an operational point of view, costs at JdR can be controlled and predicted more easily than revenues, thus the transformation of the model, in order to comply with this requirement, found crucial. Two additional *assumptions* have been adapted only to this basic model, except for the ones that have been reported above. These assumptions, are:

- There is only one type of vehicle and one type of commodity.
- There are always vehicles available to be allocated.

Consider a set of nodes representing the locations that JdR provides transportation service from/to. Let $G = (N, A)$ in which N is the set of locations and A arcs associated in the network. Locations are indexed by i, j and k and the planning horizon is assumed to comprise a finite number $0, ..., T$ of time periods, where t represents the defined time horizon of each period. Let $\tau_{ij}, i \in N, j \in N$ the travel time from point i to point j; $d_{ijt}, i \in N, j \in N, t \in 0, ..., T$ the number of of full loads/shipments (1 shipment=1 trailer) available at time period t to be moved from origin i to destination j; $f_{ij}, i \in N, j \in N$ the cost of departing a loaded vehicle from location i to j; $p_{ki}, i \in N, k \in N$ the penalty cost of ordering an empty vehicle from location k to location i. In addition to the above and comparing the model of Raoufi [22] to the one that was designed by Ghiani [33], the parameter $m_{it}, i \in N, t \in 0, ..., T$ was found important to be included in order to represent the number of vehicles that enter the system in period t at point i. In essence this parameter is used to represent both the availability of vehicles and the external flow if existing into the system. For instance a vehicle may appear later in the system because of maintenance. Obviously, during the first period $m_{it}, i \in N, t \in 0, ..., T$ includes all the vehicles that are available in the system and triggers the algorithm. This addition substitute the function of Γ_{it} from the model of Raoufi [22] since its characteristics are included in the new parameter.

The following decision variables were determined: $x_{ijt}, i \in N, j \in N, t \in 0, ..., T$ representing the number of loaded trailers to departure at time period t from location i to j; $y_{kit}, i \in N, k \in N, t \in 0, ..., T$ representing the number of empty trailers to departure at time period t from location k to j. Obviously, $y_{iit}, i \in N, t \in 0, ..., T$ represent vehicles staying idle on location i at time period t(the so-called inventory movements). The deterministic revised VAP model can be formulated as follows:

$$\min \quad \sum_{t=0}^{T} \sum_{i \in N} \sum_{j \in N, i \neq j} f_{ij} x_{ijt} + p_{ki} y_{ki} \tag{4.2.1}$$

Subject to:

$$\sum_{j \in N} (x_{ijt} + y_{ijt}) - \sum_{k \in N, k \neq i, t \geq \tau_{ki}} (x_{ki(t-\tau_{ki})} + y_{ki(t-\tau_{ki})}) - y_{iit-1} - m_{it} + y_{iit} = 0 \qquad \forall (i,t) \tag{4.2.2}$$

$$x_{ijt} \geq d_{ijt} \qquad i \in N, j \in N, t \in 0, ..., T \tag{4.2.3}$$

$$x_{ijt} \geq 0 \qquad i \in N, j \in N, t \in 0, ..., T \tag{4.2.4}$$

$$y_{ijt} \geq 0 \qquad i \in N, j \in N, t \in 0, ..., T \tag{4.2.5}$$

The objective function (4.2.1) is the total cost paid to transport orders. Constraint (4.2.2) is a flow conservation constraint at the beginning of each time period satisfying that no assets are lost, while (4.2.3) state that the demand is not higher than the number of loaded movements. All the variables are integers and positive or equal to zero. Since the new parameter $m_{it}, i \in N, t \in 0, ..., T$ was found significant to be included (for feasibility reasons), two more constraints included in this initial model. In particular:

$$\sum_{j \in N} (x_{ij0} + y_{ij0}) + y_{ii0} = m_{i0} \qquad \forall i \in N, j \in N \tag{4.2.6}$$

$$\sum_{k \in N, k \neq i, t \geq \tau_{ki}} (x_{ki(t-\tau_{ki})} + y_{ki(t-\tau_{ki})}) + y_{iit-1} + m_{it} = y_{iit} \qquad \forall i \in N, j \in N, t \in 0, ..., T \tag{4.2.7}$$

Constraint (4.2.6) ensures that at the beginning of the period the number of vehicles that will be used is equal to the available ones in the system, while (4.2.7) explicitly dictate how the number of idle/available trailers at each node of the network for each time period is formed. It is worth mentioning that the above model propose decisions using only own assets and in case that the difference $d_{ijt} - x_{ijt}$ is positive, loads should be rejected (not realistic for JdR).

4.2.2 *Revised VAP with Charter*

All freight demands at JdR are accepted by the customer service and released into the system. Since loads cannot be rejected, it can happen that the volume of these freight requests are more than JdR's own capacity, and hiring a charter company becomes a necessity. Beside that, if the costs, in comparison to the revenues of using own assets, are higher than using a charter, then it is also more beneficial to hire a charter to satisfy a particular freight request. The second version of the revised VAP is an extension made to include charter decisions. The model based on costs decides between hiring a charter or using own assets (including empty running).

Parameter h_{ij} has been added to represent the cost associated with hiring a charter from location i to location j; while the variable z_{ijt} is used for defining the number of charter needed from location i to location j. The last assumption of the base model (vehicles are always available to be allocated), apparently does not apply, since when vehicles are not available, a charter can be used; then, another *assumption* has been added and apply for all the extensions of the model from this moment on:

- Charter are always available and appear instantaneously on the location of demand (no travel time for the charter is considered)

In the new version of the model constraints (4.2.2)-(4.2.7) remain (except from (4.2.3)), while the objective and constraint (4.2.3) are transformed as follows:

$$\min \quad \sum_{t=0}^{T}\sum_{i\in N}\sum_{j\in N, i\neq j} f_{ij}x_{ijt} + p_{ki}y_{ki} + h_{ij}z_{ijt} \tag{4.2.8}$$

Subject to:

$$\sum_{j\in N}(x_{ijt}+y_{ijt}) - \sum_{k\in N, k\neq i, t\geq \tau_{ki}}(x_{ki(t-\tau_{ki})}+y_{ki(t-\tau_{ki})}) - y_{iit-1} - m_{it} + y_{iit} = 0 \qquad \forall(i,t) \tag{4.2.9}$$

$$\sum_{j\in N}(x_{ij0}+y_{ij0}) + y_{ii0} = m_{i0} \qquad i\in N, j\in N \tag{4.2.10}$$

$$\sum_{k\in N, k\neq i, t>\tau_{ki}}(x_{ki(t-\tau_{ki})}+y_{ki(t-\tau_{ki})}) + y_{iit-1} + m_{it} = y_{iit} \qquad i\in N, j\in N, t\in 0,...,T \tag{4.2.11}$$

$$x_{ijt} + z_{ijt} \geq d_{ijt} \qquad i\in N, j\in N, t\in 0,...,T \tag{4.2.12}$$

$$x_{ijt} \geq 0 \qquad i\in N, j\in N, t\in 0,...,T \tag{4.2.13}$$

$$y_{ijt} \geq 0 \qquad i\in N, j\in N, t\in 0,...,T \tag{4.2.14}$$

$$if \quad d_{ijt}=0, \quad then \quad x_{ijt}=0 \quad \forall(i,t) \quad and \quad i\neq j \tag{4.2.15}$$

As in the base model target of the objective (4.2.8) is the minimization of the total cost paid to transport orders, but in this model also the cost of hiring a charter has been included. The modified constraint (4.2.12) now determines that either own or charter vehicles will satisfy the freight requests at time period t, while the conditional (4.2.15) added for reasons of feasibility and ensures that load vehicles are used if and only if freight requests exists (avoiding unnecessary trips between locations).

4.2.3 *Revised VAP with Charter, Idle Costs and Heterogeneous fleet*

So far the two versions of the algorithm propose decisions based only on costs for moving (empty or loaded) vehicles and hiring a charter. However, for the company this is not a realistic case since trailers are always generating costs, even if they are not in use and stay idle in a location. In particular, the different type of trailers generate different idle costs where the cooler ones are the most expensive. The second extension of the model takes into account these idle costs, forcing the algorithm to give priority to the use of owned trailers instead of hiring a charter.

Additionally, for the sake of simplicity, until now it was assumed that only one type of trailer and one type of commodity were used, thus the costs of departing and running empty (consequently also idle) were the same. Nevertheless, this is not always the case, since not all the type of commodities can be assigned to the same trailers and, the different types of trailers generate different costs. Consequently, this extension, except for considering idle costs for different type of trailers, also takes into account the different costs that are generated in the same arc (loading and empty running), related to the use of different type of trailers. For instance, loading a cooler trailer yields more costs than loading a tilt or box trailer, but it also generates idle costs if it is not in use. Obviously, the matching of the type of commodity to the appropriate type of trailer is an issue that has also to be taken into account.

Therefore, for the second extension of the model it is important to define as $p \in \{1...P\}$ the type of commodity for which a freight request could exist, and as $v \in \{1...V\}$ the type of trailer (cooler, tilt, box, etc.) that are available on the system. The binary parameter $\phi_{pv} \in \{0,1\}$ determines which type of commodities can be assigned to a trailer. For instance if we use three type of trailers ($v \in \{1...3\}$) and commodity type 1 ($p = 1$) can be assigned **only** to type trailer 2 ($v = 2$) then $\phi_{12} = 1$ and $\phi_{11} = \phi_{13} = 0$. Apparently, these loading limitations are not so simple since many commodity types exist and the assignment of one (or more) of them to more than one trailer types is possible. In turn trailer types can serve more than one commodity types.

According to all the aforementioned an appropriate modification of the algorithm is needed in order to incorporate the different type of trailers and commodity. Hence, consider $f^v_{ij}, i \in N, j \in N, v \in \{1..V\}$ the cost of departing a loaded trailer type v from location i to j; $p^v_{ki}, i \in N, k \in N, v \in \{1..V\}$ the penalty cost of ordering an empty trailer type v from location k to location i; $h^v_{ij}, i \in N, j \in N, v \in \{1..V\}$ the cost associated with hiring a charter type v from location i to location j; $d^p_{ijt}, i \in N, j \in N, t \in 0,...,T, p \in \{1..P\}$ the number of full loads of commodity type p available at time period t to be moved from origin i to destination j; $c_{vi}, v \in \{1..V\}, t \in 0,...,T$ the cost of trailer type v staying idle in location i.

The following decision variables were defined: $x^v_{ijt}, i \in N, j \in N, t \in 0,...,T, v \in \{1,...,V\}$ representing the number of loaded trailers type v to departure at time period t from location i to j; $y^v_{kit}, i \in N, k \in N, t \in 0,...,T, v \in \{1,...,V\}$ representing the number of empty trailers type v to departure at time period t from location k to j; $z^v_{ijt}, i \in N, j \in N, t \in 0,...,T, v \in \{1,...,V\}$ representing the number of needed charter type v from location i to location j; $y^v_{iit}, i \in N, t \in 0,...,T, v \in \{1,...,V\}$ the number of trailers type v staying idle in location i at time t. The objective function and constraints are formulated as follows:

$$\min \quad \sum_{t=0}^{T} \sum_{i \in N} \sum_{j \in N, i \neq j} f_{ij}^{v} x_{ijt}^{v} + p_{ki}^{v} y_{kit}^{v} + h_{ij}^{v} z_{ijt}^{v} + c_{vi} y_{iit}^{v} \tag{4.2.16}$$

Subject to:

$$\sum_{j \in N} \sum_{v \in V} (x_{ijt}^{v} + y_{ijt}^{v}) - \sum_{k \in N, k \neq i, t \geq \tau_{ki}} \sum_{v \in V} (x_{ki(t-\tau_{ki})}^{v} + y_{ki(t-\tau_{ki})}^{v}) - y_{iit-1}^{v} - m_{it}^{v} + y_{iit}^{v} = 0 \qquad \forall (i,t,v) \tag{4.2.17}$$

$$\sum_{j \in N} \sum_{v \in V} \phi_{pv} (x_{ijt}^{v} + y_{ijt}^{v}) \leq \sum_{k \in N, k \neq i, t \geq \tau_{ki}} \sum_{v \in V} \phi_{pv} (x_{ki(t-\tau_{ki})}^{v} + y_{ki(t-\tau_{ki})}^{v}) + \sum_{v \in V} \phi_{pv} y_{iit-1}^{v} + \sum_{v \in V} \phi_{pv} m_{it}^{v} \qquad \forall (i,t,v) \tag{4.2.18}$$

$$\sum_{j \in N} (x_{ij0}^{v} + y_{ij0}^{v}) + y_{ii0}^{v} = m_{i0}^{v} \qquad i \in N, j \in N \tag{4.2.19}$$

$$\sum_{k \in N, k \neq i, t > \tau_{ki}} (x_{ki(t-\tau_{ki})}^{v} + y_{ki(t-\tau_{ki})}^{v}) + y_{iit-1}^{v} + m_{it}^{v} = y_{iit}^{v} \qquad i \in N, j \in N, t \in 0, ..., T \tag{4.2.20}$$

$$\sum_{v \in V} \phi_{pv} x_{ijt}^{v} + \sum_{v \in V} \phi_{pv} z_{ijt}^{v} \geq d_{ijt}^{p} \qquad i \in N, j \in N, t \in 0, ..., T \tag{4.2.21}$$

$$if \quad d_{ijt}^{p} = 0, \quad then \quad x_{ijt} = 0 \quad \forall (i,t) \quad and \quad i \neq j \tag{4.2.22}$$

$$if \quad d_{ijt}^{p} = 0 \quad and \quad y_{iit}^{v} \neq 0, \quad then \quad \sum_{k \in N, k \neq i, t \geq \tau_{ki}} y_{ki(t-\tau_{ki})}^{v} = 0 \tag{4.2.23}$$

$$x_{ijt}^{v}, \quad y_{kit}^{v}, \quad z_{ijt}^{v}, \quad \in \mathbb{Z} \tag{4.2.24}$$

$$t \in \{0...T\} \tag{4.2.25}$$

$$i, j, k \in \{1...N\} \tag{4.2.26}$$

$$v \in \{1...V\} \tag{4.2.27}$$

$$p \in \{1...P\} \tag{4.2.28}$$

$$\phi_{pv} \in \{0, 1\} \tag{4.2.29}$$

As can be observed in the objective (4.2.16) the cost of idle vehicles has been added, which is determined by the number of idle vehicles y^v_{iit} and not by the number of available trailers (Raoufi [22]). Constraint (4.2.17) is a conservation constraint, while (4.2.18) has been added as a node capacity constraint that takes into account loading limitations. Further (4.2.21) has been transformed in order to comply with the limitations that apply for assigning a commodity to a trailer, and the conditional (4.2.23) has been included for ensuring that even if there is idle cost, it is preferable the trailer to stay in one location than moving empty when no demand exists.

4.2.4 *Future Visibility and Driver Allocation on VAPCI*

In the final revision of the VAPCI model [22], Raoufi considered also future visibility along with driver allocation. The first one is an aspect that can also be taken into account in the research model, while the later is more complex and, as it was indicated by the company, it was better to exclude it from this research. Driver allocation is a really complicated issue subjected not only to European regulations, which require a strict schedule for drivers (driving hours and rest), but also to drivers, who for any reason may not be willing to execute a plan. Thus, driver allocation is a matter that can be included in the post processing set of decisions, and planners can achieve higher quality of decisions (instead of the ones that an algorithm can offer) communicating with drivers.

Future visibility, on the other hand, can add significant benefits to the existing model, taking into account the future demand of each location. More specifically, during the development of a transportation plan, planners have to consider the future demand of locations. Thus, if there is a high chance that a trailer will be send in one location, which is not expected to have demand in a later period, planners should prefer to use charter instead of owned vehicle, avoiding idle and empty moving costs. Consequently, decisions regarding the allocation of assets should also be based on the desired availability of assets in each location. In essence, the specific aspect determines the base stock level for each location (although the term is not cadet, for the specific research field of supply chain).

Since demand presents seasonal characteristics, using a mean demand μ for each type of trailer for each location and a standard deviation of this mean σ, a lower and upper bound for each type of trailer in each location can be determined as follows:

$$L_i \leq y^v_{iit} \leq U_i \tag{4.2.30}$$

where:

$$L_i = \mu^v_i - \sigma^v_i \tag{4.2.31}$$

$$U_i = \mu^v_i + \sigma^v_i \tag{4.2.32}$$

Constraint (4.2.30) has been transformed through the "new" variable y_{iit}, which determines the idle and so available trailers in each location. The variable using, upper and lower bounds, is restricted to specific prices, so in that way unnecessary movements of assets can be controlled. In addition, it is worthy to mention that upper and lower bounds can easily be transformed using the 3σ rule; a rule of thumb that is used on statistics to roughly estimate the probability of something and, that is applied to normal distributed variables. Obviously, the confidence interval (how far the values are from the standard deviation) depends on the flexibility and service level JdR wants to achieve.

(4.2.31) and (4.2.32) use only a 68% confidence interval instead of 95% or 99.7%; thus depending on the needs of the company these constraints can be transformed as follows:

$$L_i = \mu_i^v - 2\sigma_i^v \quad (95\%) \quad or \quad L_i = \mu_i^v - 3\sigma_i^v \quad (99.7\%) \tag{4.2.33}$$

$$U_i = \mu_i^v + 2\sigma_i^v \quad (95\%) \quad or \quad U_i = \mu_i^v + 3\sigma_i^v \quad (99.7\%) \tag{4.2.33}$$

4.3 REVISED VAPCI WITH GREEN EXTENSION (VAPCI-G)

After the appropriate transformations, which have been applied to the VAPCI model [22], a green extension related to the reduction of fuel consumption, can be smoothly included. The decisions offered by the aforementioned model are based solely on costs without taking into account the reduction of fuel consumption, that can offer significant cost savings and deliver important environmental benefits. Planners hardly consider this aspect during the designing of a transport plan, thus an algorithm which can generate decisions based also on that, can offer latent advantages during the planning procedure. In particular, including the following extension the algorithm will come up with solutions based both on minimization of costs and fuel consumption, considering both load and empty running.

However, as it has already been discussed, fuel consumption is a complex issue depending on many factors like driving behaviour, road type, weather conditions, etc. Some of these factors are hard to be controlled, while for others specific information exist that can be included on the extended model. In section 2 various carbon emission calculators were presented and, the one that was chosen to be applied is the NTM [24], since it provides a large database of information regarding the fuel consumption of different type of vehicles on different type of roads. The method offers a coherent way for calculating fuel consumption, taking into account road surface, load capacity utilization and empty running.

Considering all the aforementioned an extension should be included in the objective function of VAPCI model, keeping the rest of the constraints the same. Let m, u, r represent the type of road (motorway, urban, rural) and $p^{m,v,r}$ the percentage of kilometres driven on each of them; FC is the fuel consumption regarding the different road surfaces with consequential different prices for full or empty running; $LCU_{weight(psys)}$ is the load capacity utilization (percentage of full load that is carried) defined as: *physical weight (or loading meters in this case) of shipment/ maximum capacity of vehicle.* In addition, c_f is defined as the cost of fuel while D_{ij} is used to describe the distance between two locations. The objective function shaped as follows.

$$\begin{aligned}
\min \quad & \sum_{t=0}^{T} \sum_{i \in N} \sum_{j \in N, i \neq j} f_{ij} x_{ijt}^v + p_{ki} y_{kit}^v + h_{ij} z_{ijt}^v + c_{vi} y_{iit}^v + \\
& \sum_{t=0}^{T} \sum_{j \in N} (FC_{empty}^{m,u,r} p^{m,v,r} D_{ij}) y_{kit}^v c_f + \\
& \sum_{t=0}^{T} \sum_{j \in N} [[FC_{empty}^{m,u,r} + (FC_{full}^{m,u,r} - FC_{empty}^{m,u,r}) p^{m,v,r}] LCU_{weight(psys)} D_{ij}] x_{ijt}^v c_f
\end{aligned} \tag{4.3.1}$$

Considering only the green extension on 4.3.1, the model can be divided into two parts. The first part refers to empty running, while the second one to the movement of a full truck load. As can be observed on the second part also the fuel consumption of empty running has been added, since fuel consumption (consequently also emissions) related to the positioning of a truck before the actual transport take place are added to it. Load capacity utilization constitute an interesting aspect of this algorithm, since trucks usually are not full loaded and utilization of assets falls bellow 100%. In addition, it should be noted that NTM [24] offers analytical information regarding the fuel consumption of different type of vehicles in different type of road surface on three traffic flow conditions (free flow, saturated, stop and go), thus, planners will be able to decide the appropriate one.

4.4 MODEL FOR LTL

As it was already discussed in section 1.3.1 during 2013, LTL shipping accounted for about 65% of JDR's total distribution operations, with almost 30% of all shipments being below 2 loading meters. In addition, it was already proved in the performance analysis part (section 3) that the utilization of vehicles usually fall below the desired 80%. Acknowledging these facts, it seems obvious that the extension of the VAPCI model or the design of a new one, that considers LTL shipping and specifically consolidation of shipments, is crucial for the company. Looking back to the literature review and considering all the research that has been made on algorithms related to LTL shipping and cross-docking, vehicle routing problem (VRP) constitutes a basic component for all of them. However, JdR already owns a software that manages routing decisions, thus a different approach had to be found. It has to be noted that routing constitutes a critical aspect of consolidation of shipments, and this is how the idea of predefined routes came up.

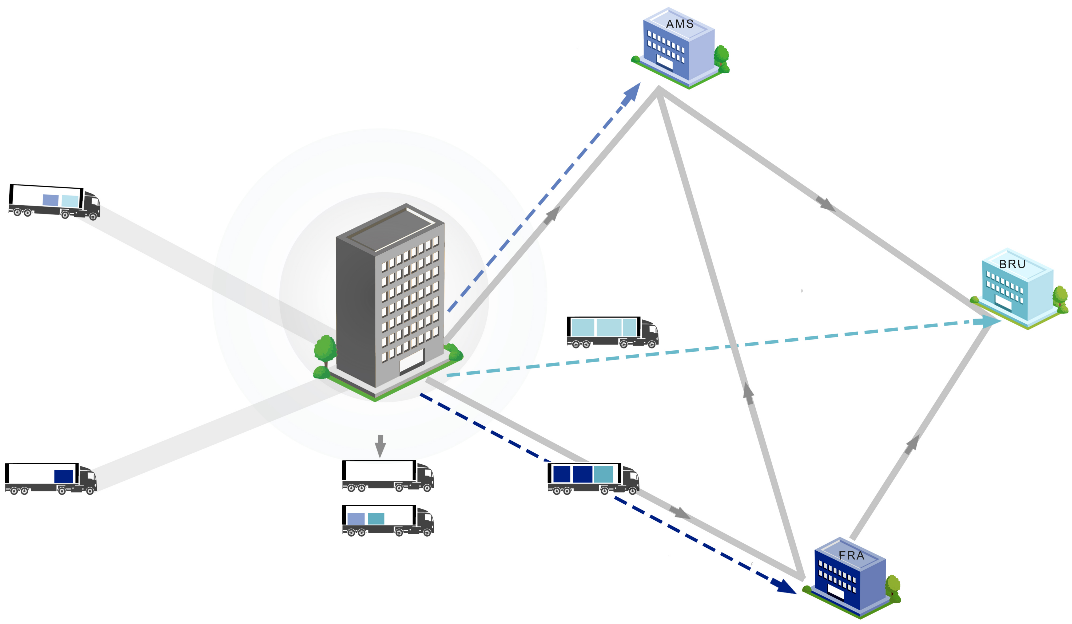


Figure 20: Depiction of LTL model, using one consolidation center and three possible destinations

Nevertheless, the issue was still hard to be formulated, since trucks that are going semi filled in one location had to be taken into account. Thus, the case that will be investigated in the following subsections is depicted in Figure 20 and, can be described as follows: one consolidation center is examined each time, but each location in the network can include this function. In this consolidation hub, idle and semi filled trucks exist, while more semi filled vehicles can appear in a later period. These semi filled vehicles are going to the consolidation center aiming to load more shipments that have the same destination, as the ones that have been already loaded, and to continue the route that they started from another consolidation center. Obviously, priority has to be given to these trucks loading the semi filled before the idle ones. Shipments are assigned to trucks according to time windows, commodity code and destination. In turn, a route is assigned to each truck. The dashed lines on Figure 20 represent direct connection between the consolidation center and one location, while the thick ones show how the routes are defined. It has to be noted that a route can include one or more stops. Consequently, when there are many shipments that are going to the same destination, the algorithm will decide to assign as much as possible to a truck that makes a route with only one stop (direct connection), instead of using one with multiple stops, due to the cost of routes.

The reference model used for this study was the Shipment Consolidation and Dispatching problem, that was introduced by Ghiani [33]. In the following subsections the model and its transformations are explained along with the extensions that have been included.

4.4.1 *Shipment Consolidation and Dispatching*

Target of the model is to find the best way of delivering timely a set of orders to the customers of JdR over a planning horizon made up of T days. As it was discussed at the company, it has been established to examine one consolidation hub (thus, one origin point); then the model needed to take into account two different aspects of consolidation regarding the available trucks that could be used, specifically:

- Idle vehicles on the hub at time $t \in T$
- Vehicles that execute a specific route and, at time t are passing by the consolidation center nearly empty (so capacity less than an empty truck). In this location, they can load more shipments with the same destination as the rest of the load in the truck, becoming a full (or nearly full) truck (FTL). Priority, thus, has to be given to these trucks.

The main assumptions of the model include:

- Truck and trailers are considered together
- Demands are deterministic and each of them corresponds to the loading meters of a shipment
- Service time (loading/ unloading) in each location has been set to zero.
- Travel time of shipments in a route are known and proportional to distance and stops order that are along the route.

Two extra assumptions only for this base model are:

- There are always available vehicles
- There is only one type of trailer and one type of commodity

The reference model of Ghiani [33] solely investigates the assignment of shipments to routes, but it was found important to also consider assignment of vehicles to routes, in order to include in the decision process the semi filled trucks. The transformed consolidation and dispatching problem can be described as follows: consider order $k \in K$ with a destination i_k, a weight/loading meters $w_k \geq 0$, a release time r_k and a deadline d_k. The company owns vehicle $v \in V$, which may follow any route r of a pre-established set R with an associated fixed cost f_{rv} and an available capacity m_{vt}. With each route r are associated a set of stops S_r, that are visited in a given order. Moreover, let $\tau_{rk}, r \in R, k \in K$, the travel time needed to deliver order k on route r. σ_v and $\delta_v, v \in V$ are the deadline and destination of the vehicles that are coming semi filled while $\mu_v, v \in V$ represents the maximum capacity of a vehicle.

The decision variables are $x_{rvt}, r \in R, v \in V, t = \{0, ..., T\}$ of binary type having a value equal to 1 if vehicle v is assigned to route r at time t , 0 otherwise; $y_{krvt}, k \in K, r \in R, v \in V, t = \{0, ..., T\}$ a binary variable equal to 1 if order k is assigned to vehicle v that is executing a route r at time t, 0 otherwise. The model is shaped as follows:

$$\min \quad \sum_{t=0}^{T} \sum_{r \in R} \sum_{v \in V} f_{rv} x_{rvt} \tag{4.4.1}$$

Subject to:

$$\sum_{k: r_k \leq t \leq d_k - \tau_{rk}, i_k \in S_r} w_k y_{krvt} \leq m_{vt} x_{rvt} \qquad \forall v \in V, j \in N, t = 0...T \tag{4.4.2}$$

$$\sum_{r}^{R} \sum_{v: i_k \in S_r} \sum_{t: r_k \leq t \leq d_k - \tau_{rk}} y_{kvt} = 1 \qquad \forall k \in K \tag{4.4.3}$$

$$\sum_{r}^{R} \sum_{t}^{T} x_{rvt} \leq 1 \qquad \forall v \in V, \forall k \in K, t = 0...T \tag{4.4.4}$$

$$if m_{vt} < \mu_v, \quad and, \quad i_k = \delta_v, \quad and, \quad \sigma_v \leq t - \tau_{rk}, \quad then,$$

$$\sum_{r: i_k \in S_r} \sum_{t}^{T} x_{rvt} = 1 \qquad \forall v \in V, k \in K, t = 0, ...T \tag{4.4.5}$$

Target of the objective (4.4.1) is to minimize the number of vehicles that are used and consequently the cost associated with them. Constraint (4.4.2) satisfies that the loading meters of the assigned to a truck shipments are not larger from the available capacity of a vehicle at that time period, considering simultaneously time windows and destination of shipments. (4.4.3) indicates that each shipment is assigned to a truck and (4.4.4) ensures that a truck is assigned only to one route but one route can be used by one or more trucks. Constraints (4.4.5) is a conditional constraint, designed to give priority to the vehicles that are coming to the consolidation center semi filled at some period t and have capacity less than a full truck. In particular, if shipments exist in the consolidation center with same destination as the ones on the truck and time windows are not violated, then these shipments have to be assigned first to these trucks and then make use of the idle vehicles' capacity (if the semi filled's one is not enough).

4.4.2 *Shipment Consolidation and Dispatching with Heterogeneity and Charter (CDPHC)*

The model that was presented above generates decisions using only owned assets, meaning that if shipments' loading meters are more than the total available capacity of vehicles, the algorithm does not gives feasible results. An effort was made to connect the VAPCI model with the consolidation model, but in that case semi filled vehicles could not be taken into account, thus the design of a model that worked independently from the VAPCI was found imperative.

As in the case of the VAPCI, it was important to also include decisions regarding charter and, costs related to the use of different type of trailers. In this final revision of the model the two aforementioned aspects are also considered. Thus, let ϕ_k describe the commodity code of a shipment k, and Φ_v a set of commodities that can be carried by each vehicle. Some new parameters need also to be defined for the charter related decisions, so h_k is the cost of transporting a shipment k with charter and ξ_k is the travel time of shipment k with charter. It has to be noted that a charter can follow any route that has been defined from the third party (3PL), thus the assignment of charter to route is not considered. The variable that is introduced for this final revision is the binary variable $z_{kt}, k \in K, t = \{0, ..., T\}$ equal to 1 if shipment k is transported by charter at time t, 0 otherwise. The consolidation and dispatching problem, considering heterogeneous type of fleet and charter decisions is formulated as follows:

$$\min \quad \sum_{t=0}^{T} \sum_{r \in R} \sum_{v \in V} f_{rv} x_{rvt} + \sum_{t=0}^{T} \sum_{k \in K} z_{kt} h_k \tag{4.4.6}$$

Subject to:

$$\sum_{k: r_k \leq t \leq d_k - \tau_{rk}, i_k \in S_r, \phi_k \in \Phi_v} w_k y_{krvt} \leq m_{vt} x_{rvt} \qquad \forall v \in V, j \in N, t = 0...T \tag{4.4.7}$$

$$\sum_{r}^{R} \sum_{v: i_k \in S_r, \phi_k \in \Phi_v} \sum_{t: r_k \leq t \leq d_k - \tau_{rk}} y_{kvt} + \sum_{t: r_k \leq t \leq d_k - \xi_k} z_{kt} = 1 \qquad \forall k \in K \tag{4.4.8}$$

$$\sum_{r}^{R} \sum_{t}^{T} x_{rvt} \leq 1 \qquad \forall v \in V, \forall k \in K, t = 0...T \tag{4.4.9}$$

$$if m_{vt} < \mu_v, \quad and, \quad i_k = \delta_v, \quad and, \quad \phi_k \in \Phi_v, \quad and, \quad \sigma_v \leq t - \tau_{rk}, \quad then,$$

$$\sum_{r: i_k \in S_r} \sum_{t}^{T} x_{rvt} = 1 \qquad \forall v \in V, k \in K, t = 0, ...T \tag{4.4.10}$$

$$x_{rvt}, \in \{0, 1\} \qquad r \in R, v \in V, t = 0...T \tag{4.4.11}$$

$$y_{krvt}, \in \{0, 1\} \qquad k \in K, r \in R, v \in V, t = 0...T \tag{4.4.12}$$

$$z_{kt} \in \{0, 1\} \qquad k \in K, t = 0...T \tag{4.4.13}$$

The objective (4.4.6) has been transformed in order to take into account cost of charter and assignment of shipments to them. (4.4.8) now impose that each order will be assigned to an owned truck that is executing a route or to a charter than can follow any route that has been decided by the carrier. In addition, all the constraints except from (4.4.9) now include the new parameters related to the commodity codes of shipments and the loading limitations that apply for each type of vehicle.

4.5 CHAPTER DISCUSSION

In this chapter the two models, that were designed exclusively for JdR, were analysed in the highest level of detail. A stepwise method was used for both, describing the extensions that were implemented. The contribution of the two models to the general research is summarized as follows:

VAPCI-G: Using a common problem that is faced by carriers (VAP), this research tried to achieve its appropriate transformation, in order to include decisions regarding third parties and heterogeneous type of fleet were achieved. In addition, future visibility, regarding the (future) needs of each location had been included in the model, as well as a green extension related to reduction of fuel consumption and consequential carbon emissions, which had been designed based on the formulation that NTM [24], had delivered so far.

CDPHC: Consolidation and dispatching is a problem that is mainly faced by producers (manufacturers) who have to choose the best way of delivering timely a set of orders to their customers. The model had been transformed according to the needs of a carrier (JdR) and, it has to be noted that the decisions generated by the model are not only quantitative but also qualitative, since they are related to the use of specific assets (truck number in the case of JdR). As in the first case the model was extended in order to take into account heterogeneous type of fleet and assignment of shipments to third parties. The use of predefined routes is a great alternative for the ones that want to avoid routing decisions, but its formulation on the optimization tool (considering both syntax and amount of information needed) was found more tough than the formulation of a simple vehicle routing problem (VRP).

With the two algorithms planners will be able to insert different type of information and examine various scenarios. Obviously, the time that the algorithm needs to generate solutions will be a significant advantage during the planning process. In the next chapter case studies with data from the company will be used to validate the necessity and efficiency of the models. For solving VAPCI-G and CDPHC, CPLEX (12.6)[45] solver will be used applying a programming language that provides a natural mathematical description of optimization models, the optimization programming language (IBM ILOG OPL v.6.3).

5

ANALYSIS OF THE PROPOSED MODELS

The two models introduced in the previous chapter were tested and validated through various scenarios. Nevertheless, it was found significant to build two cases, based on daily operations of JdR, to compare the decisions generated by the two algorithms with the ones that were taken by the planners. Thus, this chapter is dedicated to the analysis of these results. Specifically, two cases, challenging enough for the planners, were developed for the Benelux region. A multiple origin destination network for FTL was designed for the first scenario, while in the second one shipments of relatively small size had to be delivered timely from Amsterdam (consolidation hub) to three possible destinations.

Although the same region is used for both scenarios, the two cases include distinct features since the one is related to FTL shipping and the other to LTL. Consequently, the description of the cases and the results for both models are analysed in the two following sections followed by the discussion of this chapter.

5.1 VAPCI-G CASE STUDY

5.1.1 *Case Description*

The first case was designed to assess the quality of decisions that were generated by the VAPCI-G model. The case included a time horizon of 5 time periods, a multiple origin destination network with 8 locations in Benelux region (Figure 21) and, 24 freight requests (20.6 loading meters), which were released in different periods and had different characteristics. Loading limitations were defined for 4 type of commodities (pharma, engine, high tech, tobacco) and 3 type of trailers (cooler, tilt, box). Distances between locations and costs related to these distances were deterministic and known to the planners. The relationship among costs was the following:

$$c_{vi} < p^{v}_{ki} < f^{v}_{ij} < h^{v}_{ij}$$

The cost of charter, as it can be observed, was the highest since the decision to assign freight requests to charter should have been taken, if and only if it would have been necessary (trucks are not available or empty running avoided). However, it was assumed that charter was always available. Further, the cost of using a cooler trailer was 20% more than using the other two types. Simple VAPCI was examined first, followed by the green extension that was implemented in order to investigate if significant cost savings could have been obtained. Thus, in the first case the fuel cost was included in the costs per kilometres, while in the second one it was calculated independently from other costs (man power, overhead expenses etc.), but proportionally to the distance that was driven by the assets. Planners were also informed that fuel consumption was one of the main focus of the mode and doing so, they had also to take that into account during the design of the transportation plan.

Furthermore, travelling time was known and proportional to distance, but it had to be slightly relaxed, using a time period of 6 hours, in order to focus mainly on costs and allocations

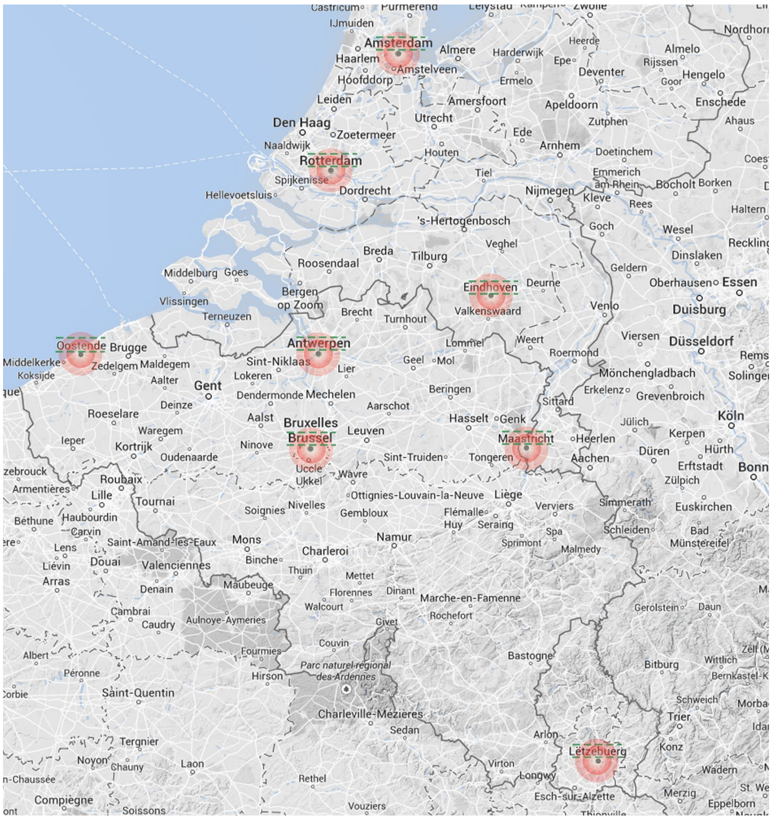


Figure 21: Multiple origin destination case study

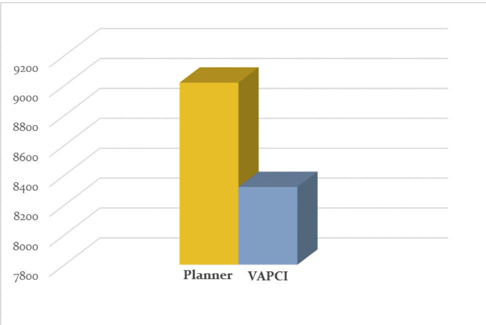
decisions. Since, the above relaxation was used for the travelling times, time windows remained strict; and this aspect was also taken into account during the evaluation of the results. Information regarding the initial inventory of vehicles in each location were available and, in total 25 vehicles could have been used in the network. During planning, planners had visibility on the demand of the next period, so that they could have decided more easily if empty running was needed for satisfying specific freight requests (of the next period). Apparently, all the requests had to be satisfied using owned vehicles or charters.

From all the aforementioned, it is obvious that the case covers all the aspects of VAPCI-G, for which the model and its extensions were designed and presented in Chapter 4. Consequently, a comparison between the decisions that were generated by the algorithm and the ones taken by the planner was found essential for drawing conclusions regarding the performance of the decision support tool. In particular the aspects that will be discussed and evaluated throughout the next section include:

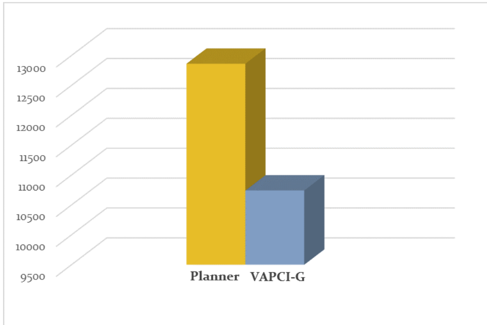
- Cost of transportation plan (both for VAPCI and VAPCI-G)
- Allocation decisions related to load and empty running
- Solution time
- Kilometres driven by assets
- Decisions regarding charter (if any)
- Fuel consumption
- On time performance

5.1.2 *Case Results*

During the development the case study, which was described in the previous section, it was decided to focus mainly on allocation decisions and investigate if cost savings could have been obtained. An experiment was conducted with an experienced planner to examine this case and, the results revealed that the decisions generated by the VAPCI and VAPCI-G outperform, in terms of costs, the ones that were taken by the planner. More specifically, as it can be seen on Figure 22 (a) cost savings of about 7.7% are achieved from VAPCI, since the total cost related to the decisions that planner took for satisfying the freight requests amounted to 9.018 € and, the one of the algorithm was 8.320 €. On the other hand, if the cost of fuel is calculated independently from other costs per kilometre, the savings are doubled to about 16.4% (Figure 22 (b)), as VAPCI-G managed to achieve a cost of 10.742 €, while planner's one increased to 12.862 €. Obviously, the significant results that were attained from both models are related to allocation decisions, thus it was found important to shed light on the decisions taken by the planner and the two algorithms.



(a) Total Allocation Cost Results, using VAPCI



(b) Total Allocation Cost Results, using VAPCI-G

Figure 22: Total allocation cost results using VAPCI and VAPCI-G

As can be observed in Figure 23, where the general allocation results are presented, planner and VAPCI have exactly the same number of load and empty running in comparison to VAPCI-G, in which these numbers are slightly lower, but assignment of freight requests to charter occurs. Consequently, the cost savings obtained from VAPCI can be charged to different allocation decisions, while the ones from VAPCI-G are charged to different allocation decisions but, they are based on reduction of fuel consumption. In order to clarify more this issue, the number of different type of trailers that was used both by the planner and the algorithms is illustrated on Figure 24.

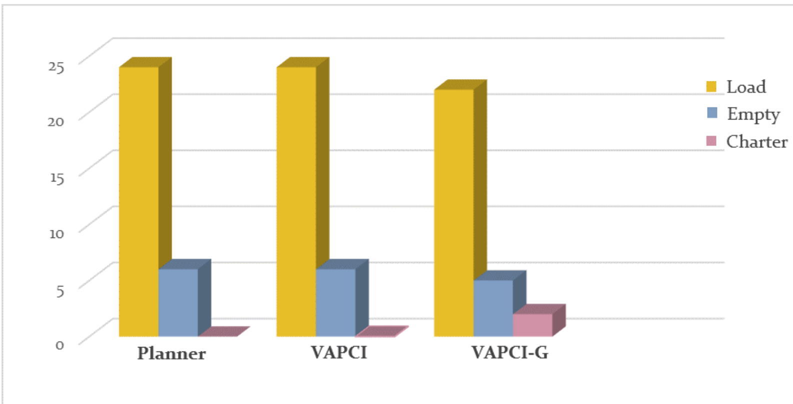
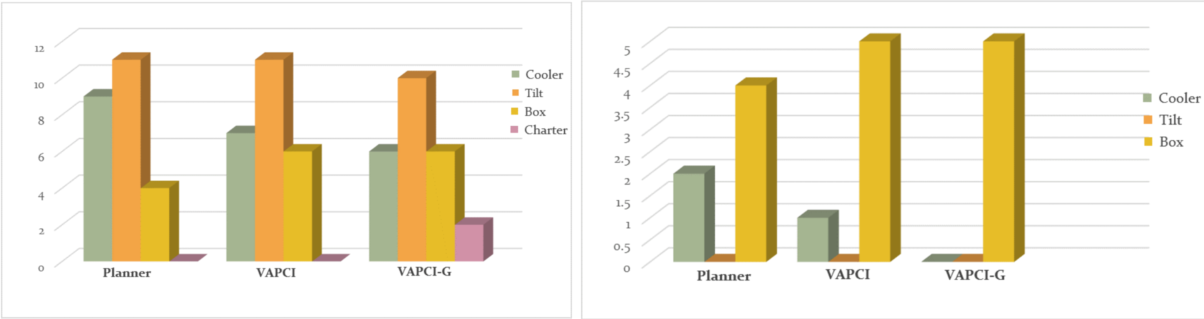


Figure 23: Allocation of load, empty and charter for planner, VAPCI and VAPCI-G



(a) Allocation of different type of trailers for planner, VAPCI and VAPCI-G (decisions for load vehicles)

(b) Allocation of different type of trailers for planner, VAPCI and VAPCI-G (decisions for empty running)

Figure 24: Allocation of different type of trailers for load and empty running

The results that can be seen in this figure validate all the aforementioned discussion as, the number of cooler trailers chosen by the planner (which are more expensive) were higher than the ones of the algorithm (2 commodity codes can be carried by both cooler and box trailer). Both planner and VAPCI did not use charter, while VAPCI-G, which takes into account fuel consumption of load and empty running, preferred to generate this solution. In general, planner and VAPCI chose to send from the same locations empty but different type of trailers to fulfil freight requests of the next periods, while VAPCI-G achieved reduction of empty running. To further investigate the above claims, it was found interesting to also estimate the total number of kilometres driven by the assets, based on the positioning decisions that was generated by the planner, VAPCI and VAPCI-G (Figure 25). Planner and VAPCI attained exactly the same number of kilometres for load running, while for the empty ones planner's decisions generated 94 additional kilometres. Nonetheless, VAPCI-G had less kilometres for both load and empty running and, thus the lowest fuel consumption (and emission levels).

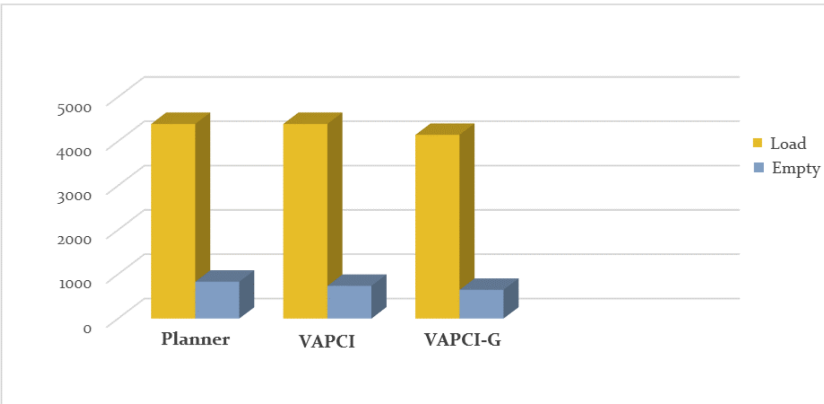


Figure 25: Number of kilometres driven according to positioning decisions of planner, VAPCI and VAPCI-G

It goes without saying that the time needed for obtaining solutions (decisions), was also an aspect that had to be examined, since such optimization models, like VAPCI and VAPCI-G, have been established as a way for obtaining fast solutions for large size problems. Planner spend about 19 minutes to came up with the decisions that was presented above, while the two algorithms needed only 4 seconds. Consequently, in terms of solution time, the two models can offer significant advantages, during the planning process. Regarding time performance, both planner and algorithms satisfied time windows, but it should be noted that the planner send late an empty vehicle to cover a freight request. In a realistic case, such transportation plan should have been re-planned, in case strict time windows would have been defined by the customer.

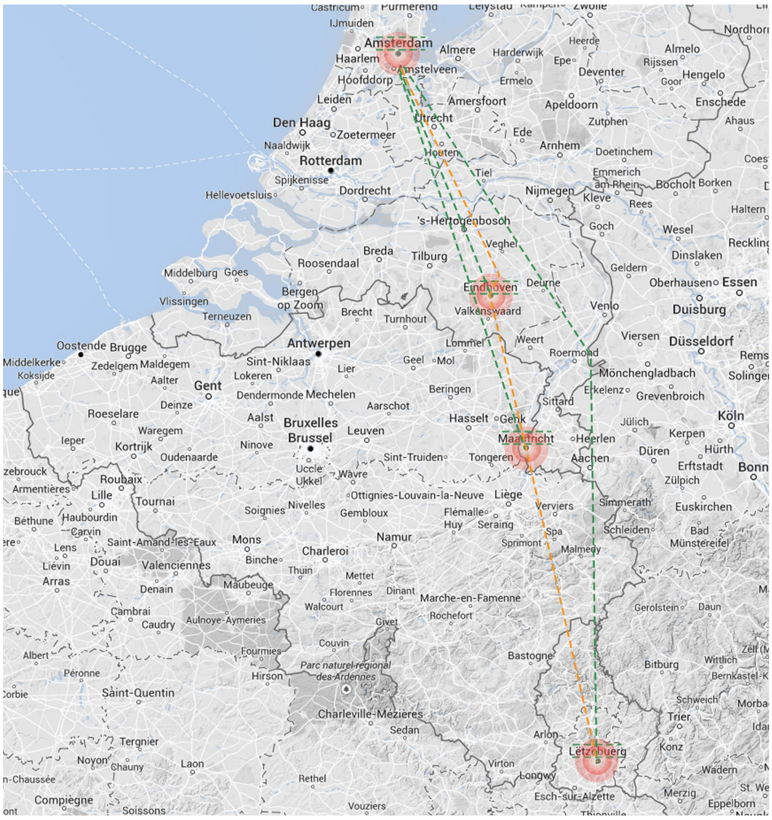


Figure 26: Consolidation and dispatching case study, with one origin and multiple destinations

5.2 CDPHC CASE STUDY

5.2.1 *Description of Case*

The second case was created to evaluate the CDPHC model and, is depicted in Figure 26. Although, some of the locations remain the same, as in the first case study, most of the other aspects have been transformed and, new ones are introduced, since the algorithm was designed for LTL shipping. In this scenario, Amsterdam is the origin point for all freight requests, where Eindhoven, Maastricht or Luxemburg are possible destinations. From Amsterdam, routes with an associated cost (proportional to distance) to each of these destinations are build trying to cover all possible scenarios (direct and indirect connections). In total 7 routes were used to indicate direct and indirect shipping; in Figure 26 the green lines symbolize direct shipping, while the orange represent possible indirect routes. Travel time is deterministic and proportional to distance and stops in a route; thus the travel time of a direct connection between Amsterdam and Luxemburg is lower compared to a route between these two cities, which includes also intermediate stop(s). Apparently, the same is happening also with the costs. Hence, transporting orders on routes with direct connection cost less than the ones that include also intermediate stations. From all the aforementioned, it is clear that the most expensive and time consuming route is the one that connects all the cities. It should be noted, during the experiment, planner had visibility both on cost and travel times associated to the use of a route. The cost of charter was assumed to be always higher, but proportional to distance and loading meters of a shipment, thus the following relationship between costs, generally held:

$$h_k < f_{rv}$$

A time horizon of 6 time periods was established, while the same loading limitations as in the first case were used, so 4 type of commodities and 3 type of trailers were defined. Consequently, the cost of a route was also correlated to the type of trailer that was used. The use of cooler trailer in a route was associated again, with a 20% increase on costs. In total, 14 vehicles could have been used in the network with 8 of them being idle in the consolidation hub, and the rest appearing semi filled in different time periods (so, priority, during loading, has to be given to the last ones). Obviously, the semi filled vehicles were headed for specific destinations after the consolidation center and, they had the same deadline as the shipments that have been already loaded into them. In addition, service time in the consolidation hub and in the intermediate stops was set to 0. In this case the freight requests increased to 30 and, each of them had the following characteristics that had to be considered during planning: destination, release time (when a shipment is available to be loaded), deadline, loading meters, commodity code.

Since the target is to compare the decisions generated by CDPHC with the ones designed by the planner, the above aspects transfuse a high level of complexity and, make the case challenging enough for the planner. In particular, both planner and algorithm, except from other aspects (cost, loading limitations etc.), had to compare and examine 150 different characteristics of shipments and, more than 56 distinct features of vehicles for achieving the best decisions regarding:

- Reduction of cost for transporting a freight request
- Increased utilization of assets
- On time performance
- Handling of incoming semi filled vehicles
- Use of Charter
- Solution time

In the next subsection the results of the case are presented and, the quality of decisions taken by the planner with the ones produced by the model are compared and assessed, according to the aforementioned aspects.

5.2.2 *Case Results*

As the first case study, the second was conducted by an experienced planner to compare his solutions to the ones produced by the algorithm. The total allocation costs for both are illustrated in Figure 27 (a) and as can be observed, the planner managed to achieve a cost of 6.848 €, while the one of the algorithm amounted only to 5.901 €. Hence, CDPHC yielded cost savings of about 14%. This difference on costs is obviously related to the routes, number of vehicles and charters that were used. In particular, the algorithm preferred to use mainly routes with direct connection that were less costly. The planner, on the other hand, since he could not find a better solution in some occasions, and in order to increase utilization of assets, was forced to use more expensive routes. Specifically, in one case, the planner chose the most expensive route (3 stops), while the algorithm avoided it.

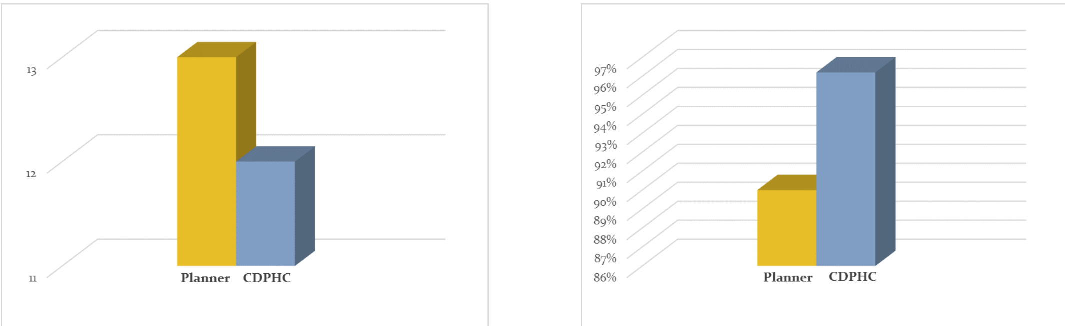
Both algorithm and planner assigned the same number of shipments to charter, but as can be noticed in Figure 27 (b), the costs of charter were higher for the planner. It has to be noted, that, in total 26 loading meters were assigned to charter by the planner, while the ones of the algorithm were 25. Thus, CDPHC chose to assign the least expensive orders to charter, achieving cost savings of about 3% (regarding charter decisions).

(a) Total allocation cost results, for planner and CDPHC

(b) Total cost of using charter for planner and CDPHC

Figure 27: Total allocation cost results and cost of using charter for planner and CDPHC

Focusing now on the number of vehicles (Figure 28 (a)), planner's decisions concluded in the use of 13 trucks, while the CDPHC made use of 12. Since the difference was small, it was found significant to further investigate this aspect, by examining the utilization levels of assets. As can be observed in Figure 28 (b), the average utilization of assets for the algorithm reaches 96% with half, of the vehicles to be fully loaded, while the others reach less than 92% [1]. The utilization for the planner fluctuated in lower values, reaching an average of 90%, with assets utilization to fall even to 69% in some cases. Nonetheless, it should be noted that the algorithm used all the semi filled trucks and almost all their available capacity, while the planner preferred to use only 5 of them.



(a) Total number of trucks used by the planner and CDPHC

(b) Average utilization of assets, for planner and CDPHC

Figure 28: Total number of vehicles used and average utilization of assets, for planner and CDPHC

Since time windows was a major issue during the designing of the decision model, it was found important to also evaluate this aspect. Examining, the decisions that were generated by the planner and the algorithm, along with the time windows (dependent on the release time, deadline and travel time of each shipment in the selected route), it was discovered that 2 of the shipments that were assigned by the planned did not satisfy this aspect. In a realistic case and, if the time windows of these 2 shipments were strict, re-planning would have been needed.

Furthermore, as in the first case study, it was found important to refer the time needed by the planner and the algorithm to generate decisions. The planner, found this case challenging enough, and took him up to 28 minutes to conclude, while the algorithm needed only 13 seconds. It should be noted that, the difference on computational time between VAPCI-G and CDPHC lies on the complexity of decisions that need to be taken by the second one, since many more parameters have to be considered.

1 For a trailer with capacity 13 loading meters, 92% corresponds to 12 fully loaded loading meters.

From all the aforementioned, it should be clear that if CDPHC is implemented in JPLEXS, it can offer significant advantages during the planning process. Generally, LTL shipping is associated with high complexity of decisions. Thus the target, during the designing of the algorithm, was to include as many characteristics of a shipment as possible, achieving cost competitive decisions that satisfy on time performance.

5.3 CHAPTER DISCUSSION

In this chapter, the description and results of two case studies that were conducted with experienced planners of the company, were presented and analysed, offering valuable insights, regarding the performance of the tools. The results, from an operational point of view appear to be promising and, it seems that both VAPCI-G and CDPHC could be proved beneficial to planners, if implemented. Table 8 provides an overview of the results for all the algorithms.

In terms of costs, both algorithms outperformed planners' decisions by generating less costly solutions. It should be noted, though, that especially for VAPCI-G, cost structure and specifically the proportional relationship among all the costs in the model, are essential for producing feasible results, which consider initial inventory and its fluctuations over time. In essence, decisions are based on reduction of costs, and solutions can be forced by implementing lower ones in some of the routes. However, the decisions produced by the two models seemed efficient enough and, special interest should be putted on the results of VAPCI-G (use of charter). Hence, planners who do not have visibility on costs, could use these solutions as indicators for designing optimized transportation plans.

In addition, the algorithm that was designed for LTL shipping managed to achieve high levels of utilization for assets and on time performance, according to the defined time windows. It is worth mentioning that planner's utilization, in some cases fall even to 69%, allowing trucks to run semi filled. Another essential advantage of both models, that should be referred, is apparently the time needed to come up with decisions. Planners spent a significant amount of time to determine the appropriate allocation decisions, while the algorithms generated optimized solutions in few seconds.

The above facts, advocate that these models, if implemented, can offer high quality of decisions, minimizing simultaneously costs and computational time. On the other hand, higher service levels could be delivered, leading to increased satisfaction of the customers and, utilization of assets can be increased, by avoiding empty or near empty running. Nonetheless, lower emission levels could be obtained for the company by applying not only VAPCI-G but also CDPHC, since the last one's target is the minimization of trucks used in the network (so, lower levels of emissions).

Algorithm	Cost Savings	Solution Time	Type of Shipping	Characteristics
VAPCI	7.7%	04:21 sec	FTL	Better allocation decisions based on costs
VAPCI-G	16.4%	04:57 sec	FTL	Better allocation decisions based on costs and fuel consumption
CDPHC	14%	12:58 sec	LTL	Better decisions regarding consolidation of shipments, utilization of assets and on time performance

Table 8: General results for the algorithms, from the case studies

6

CONCLUSION

After comparing and evaluating the decisions taken by the planners with the ones generated by the algorithms, the time has come to finalize this report by mentioning conclusions, limitations, recommendations and future research fields that sourced from, and associated to, this research. Specifically, in the next section some conclusions are drawn and, the answer to the main research question is clarified. As long as, the limitations of the research are enumerated in the follow up part, some recommendations, regarding the performance of the company are given in the third section. In the last part possible future research fields are stated.

6.1 CONCLUSIONS

As the initial target of the project was to focus solely on the challenges of LTL shipping, by designing a model that can offer substantial advantages to planners, during offline planning; eventually, it was decided to additionally transform and extend the current VAPCI model [22], in order to take into account fuel consumption and reduction of CO_2 emissions.

In the first chapter of this report analytical information regarding the transportation domain, the company, its features and planning processes were presented, in order to present sufficient acknowledgement regarding the object of study. Furthermore, the main research question was structured and the research design of this project was defined, followed by a summarized version of the literature review that took place before and during the execution of the project. The specific procedure was judged crucial for gaining insights, before the development of the decision support tools.

Additional information regarding the performance of the company was obtained in the performance analysis part, by examining freight shift scenarios and KPIs that have been defined by JdR. In that chapter, it was proved that many aspects were not comply with the standards that have been determined by the company and so, margins of improvement were identified. Further analysis of data verified that high frequency of re-planning exists, while many reasons that are associated with this issue were explicitly stated (weather conditions, long loading, freight shifts etc.).

Acknowledging and using all the above results, two models were finally developed for the company. VAPCI-G, which considers FTL shipping and, CDPHC that could offer high quality of decisions during the planning process of relatively small, in terms of loading meters, shipments (LTL). Both are cost driven models since, as it was already discussed (Chapter 4), costs information are more accessible and can be controlled more easily. However, the two models are able not only to attain cost savings, but also to reduce JdR's environmental burden. Regulations in this domain will be even stricter, forcing companies to take measures to become more "green". The contribution of VAPCI-G, regarding this aspect is obvious, since one of the features that was taken into account was the reduction of fuel consumption. However, also CDPHC can obtain significant results, regarding reduction of emissions, since its objective is the minimization of costs from using owned vehicles.

Hence, reduction on the number of moving trucks and of their consequential emissions in the network can be achieved, without jeopardizing the efficiency of company's operations.

The models were examined through various scenarios after their final formulations, but it was found also significant to design two case studies to be tested by the planners at JdR. Comparing the decisions taken by the planners with the ones produced by the algorithms, it was possible to gather many information regarding the performance of the models. More specifically:
VAPCI-G: The model, without considering reduction of fuel consumption, yielded cost savings of about 7.7%, while the percentage more than doubled to 16%, when the green extension was included. The planners could use the solutions generated by the algorithm as indicators for creating optimized and cost saving transportation plans. In addition, the results proved that better allocation decisions can be generated, avoiding simultaneously unnecessary empty running. The time that the algorithm used to produce solutions was one of the most impressive aspects, since only few seconds were needed. Consequently, planning time can be decreased dramatically allowing planners to investigate and compare different scenarios and data.
CDPHC: The cost savings of this algorithm amounted to 14%, while its computational time was higher compared to the first one, even still small (14 seconds). In addition, the decisions produced by the model showed increased utilization of assets and, better allocation decisions. Further, on time performance was achieved for all freight requests since time windows of shipments were not violated. At this point, it should be referred that the development and evaluation of the specific algorithm is linked to the answer of the main research question. Hence, in order to clarify how the planning of LTL shipping affects the performance of the company through the transportation network, the following should be indicated:

- Significant cost savings
- Reduction of planning time
- Increased utilization of assets
- On time performance
- Reduction of emissions

6.2 LIMITATIONS

This research project took place at JdR and the design of the models was based on the methods that the international transporting group use to satisfy freight requests. Thus, in other groups, different criteria are drawing planners attention; in these cases the models should be re-adapted to meet the different aspects.

Regarding VAPCI-G, it should be noted that the data that were used for the green extension were sourced from NTM method [24] and, it was assumed that each arc in the network was made up of 95% motorway, 4% rural and 1% urban roads. In addition, the trucks that were used, were considered to have the same type of engine and, consume the same type of fuel. However, it is obvious that not all the arcs have the same surface characteristics and, that not all the trucks present the above homogeneity, hence the unavailability of such information could be included in the limitations of this research.

CDPHC, on the other hand, is a decision support tool that is linked to specific needs of LTL shipping in the company. The use of one origin point was suggested by JdR for all the orders, since if the model is implemented into JPLEXS can run different simulations for multiple origin points. A further limitation of this model is that the service level was set equal to 0. Assumption that in a realistic case does not hold since the activities inside a consolidation hub are time consuming. In addition, LTL shipments that pay as FTL can not be included in the algorithm, since the model is cost and not profit driven.

However, the most basic limitation of this research was the lack of access to needed data. Although, the models were tested under real information regarding distance, travel times, capacity of trucks etc. some of the numbers (for instance costs) were fictitious. Hence, it will be interesting to examine the algorithms in a real time situation. Nonetheless, historic data were not also possible to be accessed, for assessing the performance of the models, because of the way that executed freight requests are stored in TMS. In particular, the orders that have been served remain at TMS but no information regarding the planning process of these shipments can be obtained. Thus, no information on decisions regarding re-planning or empty running could be identified.

6.3 RECOMENDATIONS

After some months working and interacting with planners at JdR, it was obvious that planning is a quite challenging process, since many aspects have to be taken into account each time a transportation plan is designed. Using the information that were collected throughout the project and the experience gained, the following recommendations to the company can be humbly mentioned:

- Planners should have visibility on the costs associated to the use of an arc/route for designing more efficient and cost saving plans.
- Transformation of the way executed shipments are stored in TMS is needed since, historic data can offer valuable information regarding the performance of the company and the way shipments were handled as well as, more precise decisions about the availability of trailers in each location (future visibility).
- Revision on some of the KPIs is needed, since at this point many aspects are excluded or not associated to each other. For instance, a rule of thumb in the company is that assets should achieve more than 10.000 km per month, but that depends also from the utilization of assets and the profitability of the transportation plans.
- Cooperation with other companies and intermodality (use of more than one modes of transportation) for moving a particular shipment, can offer significant cost savings and lead to sustainable mobility.

6.4 FUTURE RESEARCH

As it was already discussed on the first chapter, the services that are offered by the trucking companies can be generally divided into FTL and LTL. Thus, the algorithms that were created for JdR cover all aspects of shipping. However, some further research can took place for these two models. More specifically, both are integer linear programming models, so it would be important if stochasticity regarding lead times could be included. The algorithms can also be extended in order to generate decisions regarding driver allocation to trucks. However, this aspect has already been criticized, since driving regulations are complex and strict enough and, planners can take such decisions during the post processing process. Obviously, though, the green extension that was included on the objective function of VAPCI doesn't cover all aspects regarding fuel consumption and, thus some transformations or additions to the constraints should be included, as long as the company has clear targets regarding this aspect.

In addition, the algorithm that was created for LTL shipping could be extended to involve more aspects like the service times in the consolidation hubs, while a green extension similar to the one that was implemented for FTL could be applied to the model. An important feature that was not taken into account, during the development of the algorithm, because one origin point was defined, is the repositioning of assets in anticipation of the demand. Obviously, such an extension will offer more flexibility in the network, since inventories in each location can be taken into account and empty running trucks could be avoided.

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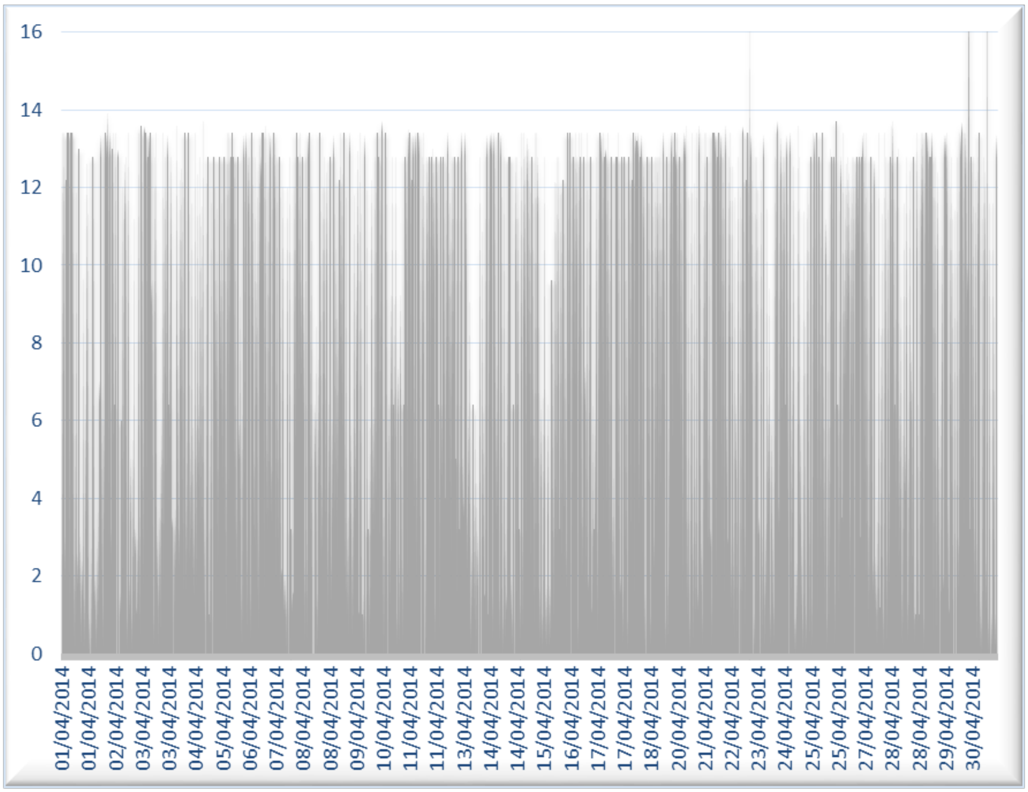
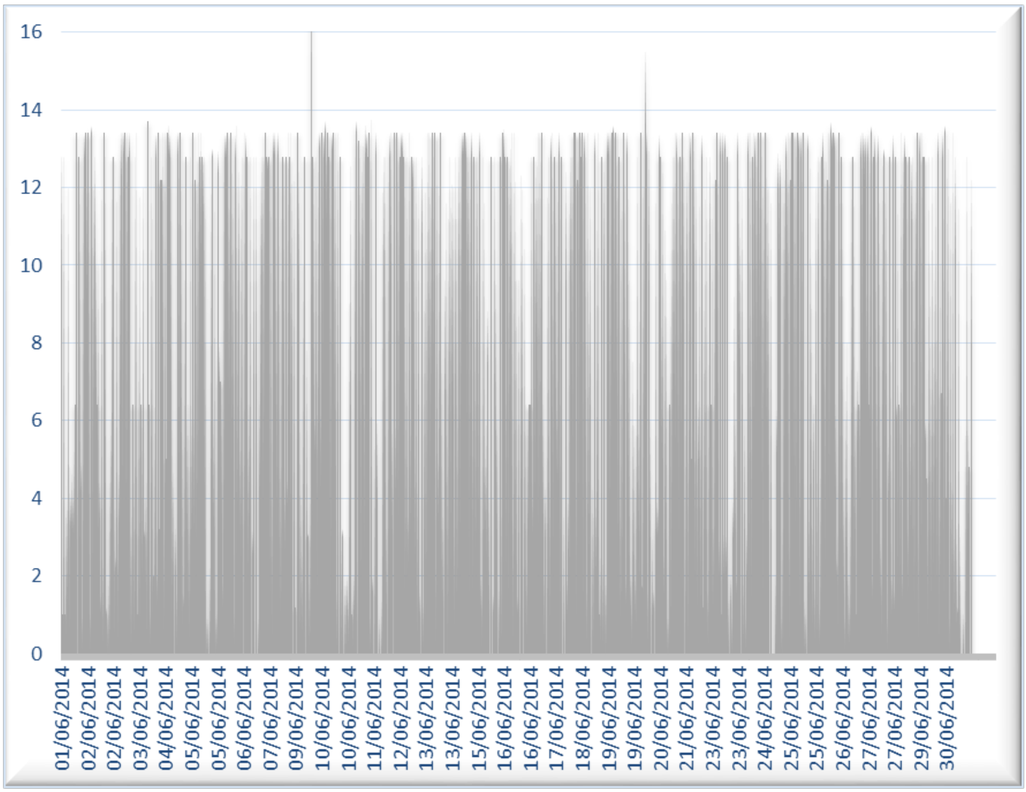
APPENDIX A



(a) Cumulative data for loading meters, April 2014



(b) Cumulative data for loading meters, June 2014

Figure 29: Cumulative data for loading meters, April and June 2014

APPENDIX B

Case Studies Data and Results

VAPCI-G Case Study

Initial Inventory	Cooler	Tilt	Box
AMS	2	1	1
ANR	0	0	0
BRU	0	3	0
EIN	1	2	3
LUX	1	0	0
MST	1	5	1
OST	0	0	0
RTM	1	2	1

TrailerType			
Loading Limitations	Cooler	Tilt	Box
Pharma	Y	N	N
Hightech	Y	N	Y
Tobacco	Y	N	Y
Engin	N	Y	N

Distance	AMS	ANR	BRU	EIN	LUX	MST	OST	RTM
AMS	0	163	203	124	415	206	285	56
ANR	163	0	42	89	266	113	128	112
BRU	203	42	0	127	230	113	127	150
EIN	124	89	127	0	305	86	212	117
LUX	415	266	230	305	0	221	351	375
MST	206	113	113	86	221	0	236	198
OST	285	128	127	212	351	236	0	234
RTM	56	112	150	117	375	198	234	0

Freight Requests				
Period	Origin	Destination	Commodity	Demand
0	AMS	ANR	Pharma	2
0	BRU	LUX	Engin	3
0	EIN	BRU	Engin	2
1	LUX	MST	Tobacco	2
1	MST	OST	Engin	5
1	RTM	BRU	Tobacco	4
2	ANR	BRU	Pharma	3
2	BRU	AMS	Engin	1
3	OST	AMS	Hightech	2

Load Vehicles Planner				
Period	From	To	TrailerType	Amount
0	1	2	1	2
0	3	5	2	3
0	4	3	2	2
1	5	6	1	2
1	6	7	2	5
1	8	3	1	1
1	8	3	3	3
2	2	3	1	3
2	3	1	2	1
3	7	1	3	1
3	7	1	1	1

Empty Vehicles Planner				
Period	From	To	TrailerType	Amount
0	6	5	1	1
0	1	8	3	1
0	4	8	3	1
1	4	2	3	1
1	3	7	3	1
1	3	7	1	1

Load Vehicles VAPCI				
Period	From	To	TrailerType	Amount
0	1	2	1	2
0	3	5	2	3
0	4	3	2	2
1	5	6	1	1
1	5	6	3	1
1	6	7	2	5
1	8	3	1	1
1	8	3	3	3
2	2	3	1	3
2	3	1	2	1
3	7	1	3	2

Empty Vehicles VAPCI				
Period	From	To	TrailerType	Amount
0	1	8	3	1
0	4	8	3	1
0	6	5	3	1
1	4	2	1	1
2	3	7	3	2

Load Vehicles VAPCI-G				
Period	From	To	TrailerType	Amount
0	1	2	1	2
0	3	5	2	3
0	4	3	2	2
1	5	6	1	1
1	5	6	3	1
1	6	7	2	5
1	8	3	1	1
1	8	3	3	3
2	2	3	1	2
3	7	1	3	2

Empty Vehicles VAPCI-G				
Period	From	To	TrailerType	Amount
0	1	8	3	1
0	4	8	3	1
0	6	5	3	1
2	3	7	3	2

Charter VAPCI-G				
Period	From	To	TrailerTyp	Amount
2	2	3	1	1
2	3	1	2	1

CDPHC Case Study

Routes & Stops			
Route	Stop1	Stop2	Stop3
1	EIN		
2	MST		
3	LUX		
4	EIN	MST	
5	EIN	LUX	
6	MST	LUX	
7	EIN	MST	LUX

Loading Limitations			
	TrailerType		
Commodity	Cooler	Tilt	Box
Pharma	Y	N	N
Hightech	Y	N	Y
Tobacco	Y	N	Y
Engin	N	Y	N

Freight Requests						
Ship.Nr	Destination(i)	Loading Meters(w)	Release Time(rt)	Deadline (dt)	Commodity Code	TravelTime with Charter
1	EIN	2	0	3	Hightech	1
2	MST	3	0	3	Hightech	1
3	EIN	4	0	3	Tobacco	1
4	LUX	10	0	3	Hightech	1
5	LUX	5	0	3	Hightech	1
6	MST	3	2	5	Pharma	1
7	MST	2	1	4	Pharma	1
8	LUX	2	1	4	Tobacco	1
9	LUX	1	0	3	Pharma	1
10	EIN	4	1	4	Hightech	1
11	MST	7	0	3	Pharma	1
12	EIN	5	0	3	Tobacco	1
13	LUX	1	1	5	Engin	1
14	LUX	3	1	4	Tobacco	1
15	EIN	9	1	4	Hightech	1
16	MST	5	1	4	Pharma	1
17	EIN	4	0	4	Tobacco	1
18	EIN	3	0	3	Tobacco	1
19	MST	2	2	4	Hightech	1
20	EIN	8	1	4	Pharma	1
21	EIN	7	0	4	Tobacco	1
22	MST	3	1	4	Tobacco	1
23	MST	4	1	4	Pharma	1
24	EIN	10	2	5	Hightech	1
25	LUX	11	0	2	Engin	1
26	LUX	3	0	3	Hightech	1
27	MST	12	1	3	Tobacco	1
28	MST	3	0	4	Engin	1
29	MST	2	1	3	Pharma	1
30	EIN	5	0	5	Engin	1

Vehicles			
Vehicle	Destination	Type	Deadline
1	0	Tilt	
2	1	Box	4
3	0	Box	
4	0	Cooler	
5	0	Cooler	
6	2	Cooler	3
7	0	Tilt	
8	0	Tilt	
9	3	Cooler	3
10	2	Tilt	3
11	0	Box	
12	0	Box	
13	2	Box	4
14	1	Cooler	3

Available Capacity						
Vehicle	0	1	2	3	4	5
1	13	13	13	13	13	13
2	0	10	10	10	10	10
3	13	13	13	13	13	13
4	13	13	13	13	13	13
5	13	13	13	13	13	13
6	0	7	7	7	7	7
7	13	13	13	13	13	13
8	13	13	13	13	13	13
9	0	6	6	6	6	6
10	0	0	9	9	9	9
11	13	13	13	13	13	13
12	13	13	13	13	13	13
13	0	0	5	5	5	5
14	0	9	9	9	9	9

Travel Time						
Route	Stop1	Stop2	Stop3	Stop1	Stop 2	Total
1	EIN			x	x	1
2	MST			x	x	1
3	LUX			x	x	1
4	EIN	MST		1	x	1
5	EIN	LUX		1	x	2
6	MST	LUX		1	x	2
7	EIN	MST	LUX	1	1	2

Load Vehicles Planner			
Vehicle	Period	Route	Shipments
1	0	3	25
2	2	1	24
3	2	1	1,3,10,18
4	2	2	6,7,11
5	1	4	23,2,12
6	1	5	16,29
7	0	7	13,28,30
8			
9	1	3	8,9,14
10			
11	1	2	27
12	0	1	5,21
13	2	2	19,22
14	1	1	20

Charter Planner	
Period	Shipments
0	4,26
1	15,17
2	
3	
4	
5	

Load Vehicles CDPHC			
Vehicle	Period	Route	Shipments
1	1	3	13,25
2	3	1	24
3	1	2	27
4	2	2	2,6,16,29
5	1	1	3,20
6	2	2	7,23
7			
8			
9	1	3	8,9,26
10	2	4	28,30
11	1	1	15,18
12	1	1	1,17,21
13	2	2	19,22
14	1	1	10,12

Charter CDPHC	
Period	Shipments
0	4,5,11
1	14
2	
3	
4	
5	

APPENDIX C

Dear planners,

In the course of the GET-Service project we are developing a platform which will provide transport planners with the means to plan transport routes more efficiently and to respond quickly to disruptions during transport (http://getservice-project.eu/).

One aim of our project is to take into account unexpected events which affect transport execution. Since you are experienced in this manner, we would like to ask you to give us some information about certain unexpected events, which you can find in the table below. We would like to obtain information about the average delay duration and frequency of the events which affect your transport operations. Therefore we would be very grateful if you could answer the following short questionnaire.

Thank you very much for your time and we would appreciate any additional feedback as it will help us to cope with the issue mentioned. The information provided by your company will be treated confidentially and anonymously.

WU Vienna University of Economics & Eindhoven University of Technology

Partners in the GET Service Project

Contact person for further information: martin.hrusovsky@wu.ac.at

General information

1. What is the approximate size of your fleet (the number of vehicles)?

2. Which transport mode(s) do you use for your transport operations?

Road: ◯ Rail: ◯ Inland Waterway: ◯ Sea shipping: ◯ Air: ◯

3. In which region(s) do you operate in Europe?

Western Europe: ◯ Central &Eastern Europe: ◯ Northern Europe (Scandinavia): ◯

Southern Europe: ◯ Intercontinental: ◯

Event-specific information

In the following part certain unexpected events are presented. For each event please approximately indicate the frequency and the delay duration on a scale from 1 to 10. 10 means that the event is the most frequent or causes the highest delay, whereas 1 represents an event which occurs very rarely or does not delay the transport at all. Additionally, for each event we would like to know how long the average delay duration is.

The term "delay duration" refers to the delay caused by the unexpected event to the plan. For example if heavy rain lasts for two days but causes the delay of the transport of only 40 minutes, then the 40 minutes are the relevant value for us.

4. Delay due to bad weather

	1	2	3	4	5	6	7	8	9	10
Frequency:	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Delay duration:	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

Average delay duration: ______________________

5. Infrastructure close-down

	1	2	3	4	5	6	7	8	9	10
Frequency:	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Delay duration:	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

Average delay duration: ______________________

Which of these events occur most often?

Closed roads:	◯	Closed lanes:	◯	Closed tracks:	◯
High/Low water level:	◯	Lock breakdown:	◯	Problems at terminal:	◯

6. Traffic accidents

Frequency:	1	2	3	4	5	6	7	8	9	10
	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Delay duration:	1	2	3	4	5	6	7	8	9	10
	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

Average delay duration: ______________________

7. Congestion

Frequency:	1	2	3	4	5	6	7	8	9	10
	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Delay duration:	1	2	3	4	5	6	7	8	9	10
	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

Average delay duration: ______________________

8. Change/Cancellation of order

Frequency:	1	2	3	4	5	6	7	8	9	10
	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Delay duration:	1	2	3	4	5	6	7	8	9	10
	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

Average delay duration: ______________________

9. Un-/Loading delays

Frequency:	1	2	3	4	5	6	7	8	9	10
	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Delay duration:	1	2	3	4	5	6	7	8	9	10
	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

Average delay duration: ______________________

10. Ferry/Shuttle delays (intermodal transport)

	1	2	3	4	5	6	7	8	9	10
Frequency:	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Delay duration:	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

Average delay duration: ______________________

11. Border/Customs controls

	1	2	3	4	5	6	7	8	9	10
Frequency:	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Delay duration:	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

Average delay duration: ______________________

12. Infrastructure maintenance

	1	2	3	4	5	6	7	8	9	10
Frequency:	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Delay duration:	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

Average delay duration: ______________________

13. Technical failures

	1	2	3	4	5	6	7	8	9	10
Frequency:	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Delay duration:	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

Average delay duration: ______________________

14. Driver failure/unavailability

	1	2	3	4	5	6	7	8	9	10
Frequency:	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Delay duration:	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

Average delay duration: ______________________

Information about critical events

In addition to the information required in the table we would also ask you to answer the following open questions. These refer to the most critical events which you have to deal with.

15. Which events are the most critical ones regarding to the execution of your transport plans?

16. Are there any particular locations where those critical events occur with high frequency?

17. Which actions are usually taken by you when those critical events occur?

Appendix (Additional Information)

General information

1. In which way of shipping are you more specialized?

FTL: ◯ LTL: ◯ Both: ◯

2. Do you follow any rules of thumb/structures while planning a shipment?

Yes: ◯ No: ◯

If yes please provide a short description:

3. How often re-planning is needed, per day (Re-planned shipments/ Total shipments planned)?

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

4. How often re-planning of FTL is needed, per day (Re-planned shipments/ Total shipments planned)?

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

5. How often re-planning of LTL is needed, per day (Re-planned shipments/ Total shipments planned)?

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

6. How many hours do you spend on average for re-planning one shipment?

7. What are the most important reasons for re-planning?

Demand Characteristics: ◯ Low Planning Quality: ◯ Delay Events: ◯

Pure information exchange: ◯ Unsatisfied time windows: ◯ Availability of assets: ◯

Other:

8. Do you have visibility on costs and revenues related to the execution of a plan?

Yes: ◯ Not, at all: ◯ No Clear: ◯

9. Which of the following do you use and consider important during re-planning?

Experience: ◯

Knowledge: ◯

Information exchange: ◯

All of them: ◯

Other:

Demand Specific Events

10. Cancellation of order

	1	2	3	4	5	6	7	8	9	10
Frequency:	○	○	○	○	○	○	○	○	○	○
Delay duration:	○	○	○	○	○	○	○	○	○	○

Average delay duration:

11. Change of order

	1	2	3	4	5	6	7	8	9	10
Frequency:	○	○	○	○	○	○	○	○	○	○
Delay duration:	○	○	○	○	○	○	○	○	○	○

Average delay duration:

12. Which is/are the most common reason(s) that lead a customer to change an order?

Change on quantity: ○

Change on time (loading/delivery): ○

Change of location (pick up/ unloading): ○

Other:

13. How many hours/ days ahead on average are you informed for a change on demand specific events?

Information about LTL shipping

14. Do you follow any strategies when specifically planning LTL?

Yes: ◯ No: ◯

If yes please provide a short description:

15. Are there any specific to LTL shipping events that cause re-planning?

16. How do you react during offline planning if a new LTL request comes into the system and there is an opportunity to make a better planning?

17. How do you cope with leftover LTL shipments?

18. Do you have any strategies regarding consolidation/ combining shipments?

Yes: ◯ No: ◯

If yes please provide a short description:

I want to **Thank** you in advance for the time you spend to fill the two questionnaires. Any additional feedback from your side is highly appreciated since new insights can be gained, facilitating the development of the mathematical model and its solution algorithm.

Kind Regards,

Stathis Dimarelis