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Vehicle Routing Problem with Time Windows in the Distribution of Steel Products

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Master Thesis

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"Progress cannot be generated when we are satisfied with existing situations."

Taiichi Ohno

Abstract

The company under study, a distributor of steel products, has in the last two years been changing its business processes thus enabling it to grow at a fast pace. The complexity of the logistics has also been increasing with the number of customers and orders, as well as the failures along the distribution process.

In Portugal, the steel industry is mature therefore products are sold as commodities – product quality and prices are similar among competitors. In this context, if any player wants to outperform competitors, business processes must become more efficient, flexible, faster and customer oriented.

Distribution planning and execution are crucial processes in this industry. On the one hand, it has implications in the cost structure, since fuel, tolls and fleet maintenance are a significant part of the overall costs. On the other hand, delivering steel products within the agreed delivery times has a direct impact on customer service and satisfaction.

The goal of this study is firstly to obtain a deeper knowledge about the distribution, namely in terms of process and cost structure. At a second stage, a major improvement opportunity was identified: optimizing the distribution of steel products from 1 warehouse to “n” customers.

Currently, allocating orders to trucks is defined by the logistics planner and the route of each vehicle by the driver himself. However, if each vehicle takes steel products to ten customers, there will be millions of possible route combinations and, obviously, optimal solutions cannot be consistently obtained by their experience. Moreover, today’s ever growing and dynamic labour market, should not imply that any company be dependent on the experience of employees. Furthermore, companies should take advantage of the improvements technology can bring to business processes.

After having analysed load planning and distribution with the support of process modelling, two phases were set in order to enable an effective implementation of an optimizer: (1) better allocation of orders to each truck and (2) optimization of each route, ensuring greater agility to react to changes in the distribution process.

Therefore, this project has two main lines of action: (1) provide a geographical decision supporting system and (2) set a linear programming model to solve a vehicle routing problem that deals with distances, time windows, service time and product features.

This project will enable this company to improve a core activity of this industry, consequently becoming more competitive as a retailer of steel products.

Resumo

A empresa estudada neste projeto, uma distribuidora portuguesa de produtos siderúrgicos, tem mudado significativamente os seus processos de negócio ao longo dos últimos dois anos, com o objetivo de impulsionar o seu crescimento a vários níveis. Com as mudanças introduzidas, a complexidade da logística, bem como as falhas associadas ao processo de distribuição, tem aumentado com o número de clientes e encomendas a entregar.

Em Portugal, o setor siderúrgico é maduro, a qualidade dos produtos e os preços são semelhantes entre a concorrência, pelo que os produtos são comercializados como "commodities". Neste contexto, para que qualquer empresa se possa tornar relativamente mais competitiva, os processos de negócio têm de se tornar mais eficientes, flexíveis, rápidos e orientados para o cliente.

O planeamento e a própria execução da distribuição são processos cruciais nesta indústria. Por um lado, estes processos têm implicações sobre a estrutura de custos, uma vez que o combustível, as portagens e a manutenção da frota têm um peso considerável nos custos totais. Por outro lado, a entrega de produtos siderúrgicos nos prazos acordados tem um impacto direto no serviço ao cliente e sua satisfação.

O objetivo desta dissertação é, numa primeira instância, a obtenção de um conhecimento mais aprofundado da distribuição, nomeadamente ao nível da estrutura de custos e do próprio processo. Numa segunda fase, o projeto foca na distribuição de produtos siderúrgicos de 1 armazém para "n" clientes.

Atualmente, a alocação das entregas aos camiões é definida por um gestor logístico e a rota pelo próprio motorista, sem meios relevantes de apoio à decisão. No entanto, se considerarmos o exemplo de um camião que transporta dez encomendas, concluímos pela existência de milhões de possíveis combinações de rotas. Como será evidente, soluções ótimas não podem ser consistentemente obtidas pela experiência. Além disso, o mercado de trabalho dinâmico que circunda a empresa não permite que a empresa esteja dependente da experiência dos seus empregados.

Depois de analisados os processos relativos à distribuição, uma oportunidade de melhoria foi identificada: a otimização das rotas que ligam o armazém aos clientes. A abordagem ao problema divide-se em dois momentos: (1) melhoria da alocação das encomendas a cada um dos camiões e (2) otimização de cada rota.

Por conseguinte, este projeto tem duas principais linhas de ação: (1) disponibilizar um sistema geográfico de apoio à decisão para melhor alocar as encomendas aos camiões e (2) formular um algoritmo de programação linear para resolver um problema de otimização de rotas, que junta distância, janelas de descarga, tempos de serviço e particularidades dos próprios produtos siderúrgicos.

Este projeto permitirá à empresa melhorar um processo proponderante nesta indústria, tornando-se, consequentemente, mais competitiva enquanto distribuidora de produtos siderúrgicos.

Acknowledgments

Having reached the last hours of preparation for my master thesis, I take this opportunity to express my deepest gratitude for all the support I have been receiving throughout my academic life. This thesis results from the efforts of years made by a large set of people, namely family and friends, who do deserve my humble recognition.

Firstly, I have to thank my parents, Amabélia and Francisco, for insisting on providing the best Education they could to their two children. My brother, a superhero, and I know that Education is the best "fruit" they could offer to us, in spite of its "bitter roots". Moreover, the strength of their love and friendship has been crucial to successfully overcome the most difficult hurdles.

The wonderful example I find every day in my grandparents have to be praised. Fortunately, I have been learning with them that building big things requires patience and constant hard work. Furthermore, I have realized with them that the sweetness of life lies in a clear conscience and excellent conduct.

Furthermore, I am grateful for sharing this sinuous path with loyal and brilliant friends. They have been essential to take me out of my comfort zone and make me an avid learner. While promoting a continuous will to improve and reinvent myself, they truly make my journey much more enjoyable.

I have had the luck of having an academic experience, always in public schools, blessed by skilled and inspiring "mentors". Therefore, I am thankful to all my Professors along the way, but this time in particular to my thesis supervisor, João Claro, for all his enthusiasm, expertise and guidance throughout this process. I could witness an obvious example of commitment and competency.

Always believed that parents and professors play different roles in our Education, although both share common burdens. At Ferpinta Group, I have met a supervisor, who embodies the virtues of an excellent Education at "home" and "school" and whose great achievements have been consequence of his discipline, resilience and humbleness. For this reason, I thank very much Nuno Ribeiro Pires for the opportunity to write my thesis with the supervision of such a brilliant leader.

Finally, I am indebted to my lovely girlfriend, Marta, for this long way of absence and attention. Fortunately, I am sure this period of time made our connection even stronger. I also have to thank her mother, Anilda, for raising such a special girl and always hosting me as close family.

It is difficult to be fair enough with all the people we cross the road with. However, I want to dedicate this humble work to everyone who directly or indirectly contributed to make it happen. I hope we all could somehow create value to our society with this dissertation project, because I do believe it only accomplishes its goal when somehow improves the context around us.

Thank you for reading!

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List of abbreviations

AS IS – Current version of a business process

BMC – Business Model Canvas

DMAIC – Define, Measure, Analyse, Improve and Control

DSS – Decision Support System

ERP – Enterprise Resources Planning

ID – Influence Diagram

INFOR LN – Current ERP of the company under study

LP – Linear Programming

VRP – Vehicle Routing Problem

VRPTW – Vehicle Routing Problem with Time Windows

TO BE – Improved version of a business process

1. Introduction

The present work proposes an approach to improve the daily distribution of steel products for a steel retailer. The company under study integrates the value chain of a wide range of steel products, linking manufacturers to end consumers. As a retailer, products in large quantities are purchased from manufacturers and then smaller quantities are sold to a large number of end consumers.

Steel retailers add value by allowing the purchase of small quantities, as well as offering services that customize the steel products. The market under analysis values price, quality, service and lead time when it comes to purchasing – as most of the markets. However, since steel products are seen as commodities, prices and quality level are similar among different players in this industry. For this reason, companies struggle to reduce time taken to deliver steel products, improve service and, of course, decrease the operational costs.

Competing in such a mature industry, with strong competition and excess of capacity implemented, is challenging. The industry needs to innovate and improve business processes in order to cut costs, improve service level and reduce lead times – a better profit margin depends on the excellence of operations. Regarding the importance of operations, distribution plays a quite important role. Distribution impacts directly on customer service, lead time and cost structure. Moreover, this industry adds value by taking products from warehouse to customers' facilities.

Hence, this project intends to improve a critical process of Ferro: the distribution planning and consequently the distribution execution. Any improvement requires previously a great knowledge regarding the object of analysis, so this project also aims at providing a holistic understanding of distribution, namely in terms of process and cost structure.

The focus of this project lies on the optimization of routes with the following approach:

- set up a decision support system (DSS) to better allocate the awaiting orders to each truck, taking into consideration geographical constraints in a more accurate way;

- process the orders assigned to each truck by using a linear programming model so that the best sequence of visits can be obtained;

1.1 Project background

Founded in 1980, headquartered in Ovar, under the designation of *Grupo Comercial Ferpinta*, Ferro is part of Ferpinta Group, nowadays a global multinational with its core business in the production of steel tube and reconigzed as one of the main players in this Industry, implemented with production units in Portugal, Angola and Mozambique, besides distribution units in Spain and Portugal.

In addition to the steel industry, the Group's activity extends to Tourism in Porto Santo and Mozambique (Hotel Vila Baleira and SAPAP, respectively) and Agriculture, through the Herculano brand, currently one of the biggest European producers of agricultural implements.

As distribution unit of steel products in Portugal, Ferro is organized in a network of seven business units and steel service centers, located in Braga, Aveiro, Viseu, Santarém, Setúbal, Portimão and Funchal, aligned in a culture of proximity to the market in which it operates and focus on customer – structuring pillars of a service of excellence that the company believes to be source of competitive differentiation. In order to satisfy the needs of the market throughout the years, Ferro has extended its range of products that nowadays includes steel tubes and channels, plates, heavy plates, rebars, merchant bars and beams, among other carbon steel products.

With a focus on customer satisfaction and loyalty, the geographical proliferation and diversified supply allow Ferro to quickly respond to the diverse challenges of the market, becoming today the main Portuguese reference in the distribution of steel products, leveraged by a framework of business with ethics and rigor, as well as with sustainability objectives, that have been distinguishing the companies of Ferpinta Group.

<table>
<tr><th>KEY PARTNER</th><th>KEY ACTIVITIES</th><th>VALUE PROPOSITION</th><th>CUSTOMER RELATIONSHIPS</th><th>CUSTOMER SEGMENTS</th></tr>
<tr><td rowspan="3">Ferpinta Industry
MEGASA - Siderurgia Nacional
COSEC - credit insurance
ARSEC - plate cutting service</td><td>Distribution Planning & Execution
Stock Management & Purchase
Customer Management</td><td rowspan="3">Fast delivery of a wide range of steel products in the whole Portuguese territory
Advisory services based on steel products' specifications</td><td>Customer Managers count on their internal staff to provide a better customer service</td><td rowspan="3">Smaller retailers and metallurgical industry
Big construction projects</td></tr>
<tr><th>KEY RESOURCES</th><th>CHANNELS</th></tr>
<tr><td>Seven warehouses
Human resources
ERP - Infor LN
Financial resources
High level of Stock</td><td>Own truck fleet, outsourced freights and seven warehouses in Portugal</td></tr>
<tr><th colspan="3">COST STRUCTURE</th><th colspan="2">REVENUE STREAMS</th></tr>
<tr><td colspan="3">Raw material, Transportation, Utilities, Maintenance, Headcount</td><td colspan="2">Steel Products</td></tr>
</table>

Figure 1-1 - Business Model Canvas

Explaining in further detail the business model canvas (Osterwalder, & Pigneur, 2010) presented in Figure 1-1, FERRO has been ***building strong connections*** with suppliers (Ferpinta Group, Megasa, Arcelor Mittal, ARSEC…) in order to ensure product quality, desired lead times and service. Moreover, this engagement with a narrow range of suppliers allows the access to higher commercial discounts.

The main concern for the present Board is counting on a well prepared workforce, putting focus on recruitment and training. In a very dynamic and global context, it is vital to work along with the best human resources. They are not only the ones who daily negotiate on the buy-side and sell-side, but also the ones who struggle to make the structure which supports the core business more efficient.

In spite of having been investing a lot in technology (ERP, tracking system, barcode…), the organization is aware of the importance of human resources to adapt technology to internal needs. Therefore, the required digitization of business processes and continuous improvement culture are based on the excellence of human resources and availability of the required technological means.

Although steel products are seen as commodities, there is a countless list of specifications and particularities that the workforce should be aware of, in order to better support customers. Focus on market needs and real capacity to advise customers are features highly valued by the market.

Furthermore, since selling steel products involves transactions with large amount of money, it is crucial to define well the payment method, as well as insuring sales – Ferro trusts COSEC insurance services. Purchasing and stock management plays unquestionably a main role in this industry, since they have a great impact on profit margin. At this point, the financial capacity of Ferro is decisive, since it is allowed to invest in stock and consequently faster serve the customers.

As a retailer, Ferro currently delivers hundreds of tonnes of steel per day. The distribution is ensured by a proprietary truck fleet in each depot - Funchal does not have proprietary fleet -, as well as outsourced transportation services.

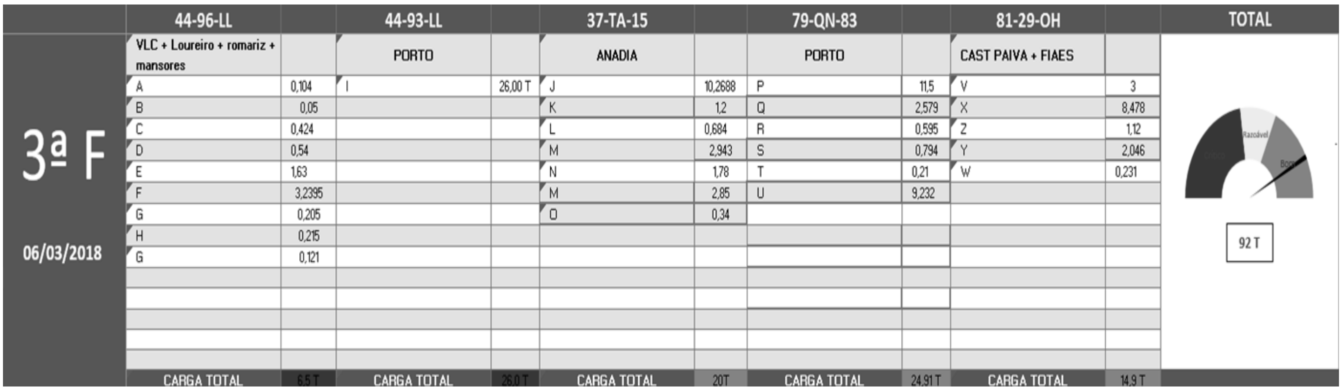
Ferro adds value by delivering the right product in the right place at the right time. However, it is important to deliver the products at the minimum possible cost in order to increase the profit margin. This dissertation aims at improving the distribution process and keeping ***building strong connections*** with customers.

1.2 Problem description

From each depot, Ferro delivers dozens of orders a day. Each truck transports up to fifteen orders to be delivered in Portugal and some points of Spain. The large number of addresses a truck may have to pass by may lead us to millions of alternative routes. Among the millions of alternatives, only one has to be chosen. How may the logistics planner and truck drivers consistently make near optimal decisions?

Every day, it is planned what (product), how (transportation means), where (customer's address) and when (time windows) to deliver in the following labor day, so a method that allows a fast, cheap and good answer to these questions is necessary.

Currently, in this distribution planning process, the orders from towns close to each other are aggregated until reaching the capacity of the trucks – see Figure 1-2. Afterwards, the drivers decide the sequence of distribution - always based on their experience.



	44-96-LL		44-93-LL		37-TA-15		79-QN-83		81-29-OH		TOTAL
3ª F	VLC + Loureiro + romariz + mansores		PORTO		ANADIA		PORTO		CAST PAIVA + FIAES		
	A	0,104	I	26,00 T	J	10,2688	P	11,5	V	3	
	B	0,05			K	1,2	Q	2,579	X	8,478	
	C	0,424			L	0,684	R	0,595	Z	1,12	
	D	0,54			M	2,943	S	0,794	Y	2,046	
	E	1,63			N	1,78	T	0,21	W	0,231	
	F	3,2395			M	2,85	U	9,232			
	G	0,205			O	0,34					92 T
	H	0,215									
06/03/2018	G	0,121									
	CARGA TOTAL	6,5 T	CARGA TOTAL	26,0 T	CARGA TOTAL	20T	CARGA TOTAL	24,91 T	CARGA TOTAL	14,9 T	

Figure 1-2 – Current distribution planning method

1.3 Project objective

This project was developed in Ovar, but data from other business units will be used to better justify some points. Ovar is frequently where the experiments are tested before being implement in other business units.

The main purpose of this dissertation is improving the distribution process by better planning the distribution. In this context, better planning should lead to serve at least the same customers and orders in the lead times agreed with less resources: fuel, tolls, fleet maintenance, labor hours and fines, among others.

This project is intended to reengineer the distribution process so that the company can consistently ensure near optimal solutions for the vehicle routing problem identified. Consequently, the company will not only reduce the dependency on the employees' experience, but also leverage the accumulated experience of the employees directly involved in the distribution process.

The tools developed to solve the Vehicle Routing Problem (VRP) should be integrated in the current distribution planning process, ensuring the value added by the tools is easily comprehended and the effectiveness does not reduce the efficiency of the process. Moreover, this tool should not only contribute to a better planning before the truck leaves the depot, but also to rapidly adjust the route when some variable or constraint changes along the way.

Furthermore, since there is not currently a formal route plan to be compared with the drivers' route and to control the drivers' choices, this project also aims at creating this daily route plan for each truck.

Finally, from the customer point of view, this project is intended to improve customer service by better managing information from two perspectives: (1) share more added-value information with the customer (expected lead time, current location…) and (2) better use of customer´s information to better plan the route (time windows, expected service time, local constraints…).

1.4 Methodology

In order to accomplish the previously stated objectives and therefore meet Ferro's expectations, this project has the following methodology (figure 1-3):

Figure 1-3 - Project methodology

Firstly, it was essential to identify, understand and internally debate the problem behind this project. Although it was widely known that the distribution process was failing in several ways, it was not clear why it was failing and which problems could be overcome by improving distribution planning. Indeed, the distribution process is connected to many others: commercial, financial, purchase, stock management and administrative, among others.

For this reason, the first challenge of this project was to find one specific problem to tackle, where more value could be added. In this step, process mapping allowed to point out the several problems and set the vehicle routing problem as the one to deal with.

Secondly, aligned with the previous explanation, it was important to define well the variables and constraints which directly and indirectly influence the chosen problem. At this stage, an influence diagram allowed to understand the impact on route planning of the identified variables and constraints and set distances and time between customers as the relevant variables and time windows, service time and product features as the relevant constraints.

Thirdly, the challenge was to understand how we could approach the VRP, taking into account the relation of route planning to other processes, in a way we could make this project independent on the other processes, as well as on its respective problems. Therefore, it was decided to firstly allocate the orders to each truck with the support of Google MyMaps and secondly solve the VRP for each truck with the support of an optimization tool built with Excel Solver.

After having developed a data visualization tool to improve order allocation and an optimization tool to minimize the time necessary to serve a set of customers allocated to a truck, these two tools were tested in a controlled environment without disrupting the normal operations of the company.

However, all the data, procedures and tools managed were the same as if it were in daily operations. For this reason, we were able to assess the feasibility of implementing these.

1.5 Report outline

The present report is structured as follows:

- Chapter 2 covers the literature review of the main themes of this project. We will move from a holistic comprehension of the steel industry to a detailed understanding of steel products retailing and from algorithms in general to optimization approaches which aim at solving the Vehicle Routing Problem (and its extensions) in particular. Finally, some examples in literature related to VRP in steel industry will be discussed.
- Chapter 3 provides a broad study of the current distribution context at Ferro. This process will be mapped in its AS-IS version and subsequently will be analyzed in order to identify the root causes behind the problems identified in the process.
- Chapter 4 presents the methodology which allowed to identify the problem, find out the root causes behind the problem, study alternative solutions to overcome the root causes of the problem and improve the process and finally test the solutions.
- Chapter 5 comprises the solutions developed to make the process more efficient and effective, presenting a comparison between two scenarios: distribution process with the solution developed and without it.
- Chapter 6 concludes this dissertation report by highlighting the achievements of each proposed solution and its impact on the project goal. In this section, relevant topics for future development will be also pointed out.

2. Literature review

The present chapter focuses on the literature about the key concepts that are relevant to explain why Ferro, as a retailer of steel products, can improve distribution planning by solving the VRP identified in this process.

It will firstly explore the features of steel industry with emphasis on the distribution of steel products, since it is the stage where Ferro is positioned in the value chain.

After having explored the industry, the importance of aligning technology with business processes in order to make them more efficient and effective will be studied. In particular, the advances in solutions to the VRP will be highlighted.

Finally, we will present some literature whose study was focused on optimization applied to solving VRP in the steel industry.

2.1 Steel industry

Steel industry has been linked to the progress of humanity for decades (Popli, & Popli, 2015). Most of the infrastructures of the modern world are based on the development of this sector and, for this reason, steel is said to be the backbone of civilization in the universe (Warren, 1987).

To better understand the influence of steel industry in the world dynamics (Diamon, J. M., 1998), steel should be understood as the resource behind construction (e.g., houses, factories, hospitals and bridges), transportation means, machines, weapons and tools, among others. The steel consumption of a nation is definitely an important indicator of economic growth and human development.

In Europe, in particular, steel is linked to the origin of the European Union. In 1951, after a bloody and devastating war, six European countries agreed to centralize the regulation of their industrial production of coal and steel in a common authority – European Coal and Steel Community (Spierenburg, & Poidevin,1993). At the time, it was understood that competition for resources among European nations had to be stopped in order to guarantee a peaceful territory. Robert Schuman declared this treaty would “make war not only unthinkable but materially impossible”.

2.1.1 A global perspective

Regarding steel production, China is the biggest producer of crude steel as we can infer in Table 2-1 (World Steel Association, 2018). Japan comes second, India third and the United States fourth with an annual production that is less than 10% of China’s. The weight of China’s production represents 49.2% of worldwide production.

In spite of being the biggest producer worldwide, China is not a rich country in terms of Iron Ore (Reuters, 2017). For this reason, China is highly dependent on the import of Iron Ore, importing a slice of 66% (World’s Top Exports, 2018). Another way to produce steel is with scrap, but China has still limited postconsumer steel materials – only 11% of its steel is produced from scrap (Reuters, 2017). This set of constraints makes us ask ourselves how China can be the biggest steel producer.

Table 2-1 - Top 10 steel-producing countries in 2017

Rank	Country	2017 (Mt)
1	China	831,7
2	Japan	104,7
3	India	101,4
4	United States	81,6
5	Russia	71,3
6	South Korea	71,1
7	Germany	43,6
8	Turkey	37,5
9	Brazil	34,4
10	Italy	24

China comes also first when it comes to steel consumption. The United States ranks second, India third and Japan fourth. Once again, the weight of China in the global demand for steel products is significant (World Steel Association, 2017).

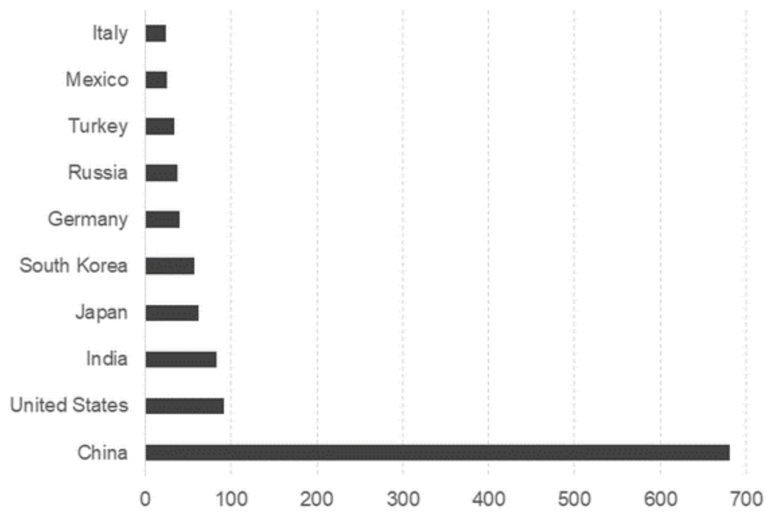


Figure 2-1 - Top 10 steel consuming countries in 2016

In million metric tons

As far as steel consumption in the European Union is concerned, Construction represented 35%, Machinery 14%, Automotive 18%, other transports 2%, Tubes 13%, metallic products 14%, household appliances 3% and others 2%, in 2016 (The European Steel Association, 2017).

Regarding major current concerns, European Union and Industry representatives are alarmed by the global excess capacity, which led the European Union to implement anti-dumping tariffs in order to avoid importing steel from countries with surplus such as China, Russia, Ukraine, Brazil and Iran (European Comission, 2018). Longer-term viability and efficiency level of the industry is threatened by the excess capacity registered in some countries (OECD, 2015) – the world capacity doubled since 2000. Moreover, the USA implemented high tariffs to discourage steel imports and protect national industry, in a setback to the globalization process (BBC, 2018).

2.1.2 Portugal in the global context

Regarding Portugal, the production of crude steel was 2 010 thousand tons in 2016, whereas the consumption of crude steel was 2 405 thousand tons, representing a per capita consumption of 231.8 kg according to the World Steel Association (2017). In Portugal, the most important producers of crude steel are Siderurgia Nacional and Lusosider in the long and flat products, respectively.

For instance, Spain had a per capita consumption of 291.6 kg and the Czech Republic had 727.6 kg, which was the highest value in Europe. South Korea was the global leader in terms of per capita consumption of steel, with 1171.8 kg (World Steel Association, 2017).

2.2 The role of retail

In fact, the world without steel has become unimaginable. However, there is usually a big distance between the steel minefields and customers (Voronov, 2012). For this reason, logistics and supply chain management have become an essential piece in steel industry (Steel World, 2009)

In the beginning of the second half of the last century, the retailers of steel products were focused exclusively on connecting manufacturers to consumers. However, in the following decades, the industry registered the entrance and growth of steel service centers, which could add and deliver value not only by storing but also by turning the steel into a size or shape specified by the customer (Stefko, Slusarczyk, Kot, & Kolmasiak, 2012).

In the last decades, the advantage of manufacturers has been growing, but it does not remove the importance of steel products distributors. Currently, the market requires the coexistence of manufacturers and retailers – their cooperation is essential (Stefko, Slusarczyk, Kot, & Kolmasiak, 2012). Whereas manufacturers mainly sell steel products to big retailers, retailers take advantage of the access to a wide range of steel products, geographic proximity and value-added services to deliver smaller orders.

2.2.1 Supply chain and logistics

Delivering value in this industry highly depends on managing well the supply chain, which connects the multiple points of the steel value chain. Supply chain is understood as a set of players which include mining, manufacturing, trading, service companies and, of course, the customers (Gajdzik, & Grzybowska, 2012). The creation of value results from a sequence of relationships and dependencies among different enterprises (Jacobs, Chase, & Lummus, 2014).

Logistics is explained as a part of the supply chain process, which includes: planning, implementation and control of the forward and reverse flow of the goods in an efficient and effective way, as well as the storage of goods (Soltany, Sayadi, Monjezi, Hayati, 2013). Moreover, it controls the information between the warehouse and the point of delivery in order to meet customer requirements (Cooper, Lambert, & Pagh, 1997).

2.2.2 Transportation

It is the transportation of steel products that determines the efficiency of moving products (Tseng, Yue, & Taylor, 2005). Transportation costs represent up to 15% of the operational costs in the European steel industry (European Steel Association, 2018). In this industry, Europe uses an intermodal platform to serve the customers, making use of three means: rail, road and water. In the European Union, the steel sector is the main user of rail freight, with 22.1% in 2006, whereas steel amounted to 5% by road and around 15% by waterways. The delivery to end consumers is mainly ensured by road.

Furthermore, as a very pollutant activity, transportation requires new approaches that help mitigate climate change and contribute to a more efficient use of resources – the steel industry has often been the subject of criticism for its environmental performance. Perhaps, expectations of tighter environmental regulations may encourage firms to invest more in new and cleaner processes (OECD, 2016).

2.3 Digitization of business processes

In fact, internet and information systems have had a great impact on business processes in general (Kangermann, 2015). Communication along the value chain has become faster and business processes more efficient and effective. Digitization allows business processes to be more flexible and able to respond in real time to changes in the market, as well as to become closer to customer needs (Uckelmann, 2008).

In spite of the challenges the steel industry is passing through, investing in digitization helps the players keep competitive (Ernst & Young, 2018), lowering their future capital requirements and operational costs (OECD, 2016).

Fast business processes allow the players to react earlier to changes in the industry environment, such as price fluctuations and variations in customer needs. The path of change and innovation has been closely associated to digitization. Companies more oriented to innovation tend to obtain better results than other companies in volatile contexts (Pires, 2012) – steel industry is a dynamic and volatile industry.

2.3.1 Algorithm

An algorithm is a numerical method that can be used to solve a problem. Moreover, it is a set of complete and clear procedures which lead to the solution of a mathematical problem. The mathematical model formulation of a physical situation is always intended to solve a well-defined problem. The quality of the output of an algorithm, which is supposedly the solution for the problem, depends not only on the quality of the mathematical model, but also on the quality of the inputs – "garbage in, garbage out" (Back, Hammel, & Schwefel, 1997).

The application of algorithms relies on the processing capacity of computers. Most of the complex problems are only solvable in a short time lapse, when the set of instructions are interpreted and processed by a computer. For this reason, programming is indispensable to overcome complex problems (Conte, & Boor, 2017).

2.4 Vehicle Routing Problem

The route planning is a problem related to choosing the locations as well as the sequence in which each truck will visit them, in order to minimize the transportation costs. In the academic literature, this is known as the Vehicle Routing Problem, a topic that was introduced by Dantzig and Ramser, in 1959 (Laporte, 1992). At the time, they proposed the first mathematical programming formulation and algorithmic approach for the solution of a real-world problem, regarding the distribution of gasoline to gas stations (Toth, & Vigo, 2002).

Since then, this notoriously difficult problem has been counting on the interest of a broad range of researchers. Solving the VRP has become a key to efficient transportation management and supply chain coordination (Golden, & Wasil, 2008).

According to literature, the application of a VRP model may lead to a cost reduction from 5% to 20% in the overall transportation costs (Carić, Pašagić, & Lanović, 2004).

2.4.1 Extensions of VRP

Significant attention has been given to various extensions of VRP. These attention and interest are justified by the economic benefit that can be achieved by optimizing the routing problems (Desrochers, Desrosiers, & Solomon, 1992).

These extensions are motivated by the particularities of each business, which imply different variables, constraints and even objectives that should be integrated in the mathematical formulation of the VRP (Gendreau, Potvin, Hasle, & Lokketangen, 2008). Among many other challenges that could be explained here, some of the challenges faced by companies, which influence the mathematical formulation, are as follows:

- Fleet: the trucks from a company may vary in terms of capacity, cost, start and end depots, for instance (Walcarius, Howbraken, Audenaert, Pickavet, & Demeester, 2013);
- Drivers: the drivers cost may depend on kilometers, work hours, number of stops on the route… and penalty costs for failing objectives may exist (Montemanni, Gambardella, Rizzoli, & Donati, 2005);

- Service times: the time to deliver (or pick-up) an order depend not only on the features of the order but also on the customers' (Francis, Smilowitz, & Tzur, 2008);
- Time windows: customers and depots may have opening hours that vary per day of the week, and an order may need to be delivered within a time windows (Cordeau, Laporte, & Mercier, 2001);

2.4.2 VRP with time windows

The vehicle routing problem with time windows (VRPTW) results from a generalization of the classical VRP, where the order delivery has to be within a time windows, which represents the earliest and latest times a customer allows the company to deliver the order/start the service (Sandhya, 2013). In other words, the VRPTW is the extension of the VRP in which each customer is associated to a time interval, called time windows. An additional service time for each customer is given. The service of each customer must start within the associated time windows and the vehicle keep stopped at the customer location as long as the service time. Moreover, in case of early arrival at the location of customer, the vehicle is generally allowed to wait until the time windows open (Lau, Sim, & Theo, 2003).

2.4.3 VRP in the steel industry

There is some academic literature regarding the application of VRP in the steel industry. On the one hand, we realize that the practical usefulness of VRP goes beyond the problems centered on customers' orders delivery. On the other hand, it is clear that the steel industry has been tackling vehicle routing problems with algorithms backing. At this stage, three applications of VRP in the steel industry will be introduced:

(1) Roljic, Tricoire and Doerner (2018) developed a model which optimized the transport of heterogeneous steel products within the factory, taking into consideration a certain number of vehicles and a capacity limit for each. Under this study, there were three objectives: maximize profit, minimize the fleet size and minimize travel times. This study led to significant improvements in the steel player under analysis.

(2) Yao-rong Cheng, Bo Liang and Mei-hua Zhou (2010) developed an algorithm to solve the vehicle routing problem with pick-up and delivery of steel in order to solve internal logistics problems in large-scale factories from China. These authors could reduce the distance travelled by 43.5%.

(3) Liang-Liang Fu, Mohamed Ali Aloulou & Chefi Triki (2017) studied a problem in the metal packaging industry, whose finished products were delivered in batches to several customers with heterogeneous vehicles, respecting respective time windows. In the company under study, solving a vehicle routing problem with time windows was essential to better coordinate production and distribution. The objective of this project was to minimize the setup time in production and the transportation cost in distribution.

2.5 Gaps in the state of art

Steel industry has been widely researched in the different stages of its value chain. For this reason, the available knowledge supports a good understanding of the industry and respective problems and opportunities. Moreover, the VRP has also been studied for decades and the proposed state of art solutions have been helping several companies performing better worldwide.

However, the VRP behind the distribution of steel products from depot to multiple end consumers has not deserved the attention of researchers. Therefore, here lies not only an opportunity to help Ferro improving its logistic operations, but also to contribute to the state of art of this industry.

3. Problem

For this dissertation project, Ferro proposed a main challenge: analyse and improve the distribution planning in order to reduce the failures directly or indirectly related to the process, as well as the costs associated to the distribution itself.

In this section, we will firstly analyse the consequences related to distribution problems, taking into consideration two sets of data: (A) departure time of trucks and (B) credit notes issued. Both are symptom of errors along the process and do not definitely add value to customers. Therefore, we will primarily recognize there is a problem to deal with.

Afterwards, we will look into the causes that may explain the consequences above, in order to correctly identify what is behind the problem identified. At this stage, the distribution process will be mapped and detailed.

Finally, since having a more holistic comprehension of the distribution process is a main goal in this project, the fleet and distribution cost structure will be presented and analysed.

3.1 Problems in distribution – consequences

Since 2016, Ferro has been considerably changing its business processes. This is consequence of an effort that has been made to widen the range of products supplied as well as customize some of the products, which led to an increase in revenues and orders delivered. These new directions have had a positive impact on the complexity of Ferro’s business model in general and on its distribution process in particular.

Throughout this dissertation´s time, the company has been making a big effort to improve this process, by setting logistics managers/planners in each business unit and digitizing the distribution planning process. Meanwhile, there was actually a “feeling” that the process was getting better with these changes.

The available data takes us to a different conclusion, although it may be too early to infer that these changes will not improve the process, since the team is still adjusting to a new way of working and the available data refers to a short period of time.

Nonetheless, we decided to analyse two different sets of data in order to prove that in Ovar the distribution planning process is not better in the end of July than it was in the beginning of February. The first table presents the departure time of trucks, since it is when the drivers start their way to deliver the orders, whereas the second table shows the credit notes issued - with emphasis on logistics -, since a credit note is always related to an error.

3.1.1 Trucks departure time

Table 3-1 - Average departure time of trucks in Ovar

	February	March	April	May	June	July
Driver A	8:35	9:01	8:44	8:52	8:38	8:50
Driver B	8:48	9:10	8:54	9:11	9:15	8:45
Driver C	8:41	8:38	8:42	8:47	8:42	8:45
Driver D	8:46	8:46	8:57	8:44	8:37	8:43
Driver E	8:54	8:56	9:05	8:59	8:53	8:55
AVERAGE	**8:45**	**8:54**	**8:52**	**8:54**	**8:49**	**8:48**

In the table above (3-1), we observe an increase of three minutes on average between February and July in all the truck departures from Ovar – everyday, 5 trucks usually leave Ovar in the morning. Firstly, since the drivers start working at 8am, it means that each driver is wasting three more minutes in July than in February. For this reason, each driver has less three minutes on average to distribute all the orders in a day of 8 labour hours. However, if we take into account the total time wasted in July, forty eight minutes on average, we conclude that 10 % of drivers' time was wasted in May. This shows there is margin to deliver more by eliminating this waste.

3.1.2 Credit notes issued

Table 3-2 - Number of credit notes issued in Ovar

Cause\Period	Aug – Oct 2017	Nov–Jan 2018	Feb – Apr 2018	May – Jul 2018
Invoice	14	5	21	19
Price	62	66	29	48
Product quality	13	11	17	24
Customer order	4	6	11	20
Logistics	13	24	23	24
TOTAL	**106**	**112**	**101**	**135**

There was an increase of 27.4% in the number of credit notes issued between the period of time August-October 2017 and May-July 2018 (Table 3-2). Nevertheless, this increase was not even higher because price corrections were significantly reduced in this same period – less 22.6%.

All the other causes registered a significant increase. Errors in issuing invoices have augmented 35.7%, problems caused by product and suppliers' quality have increased 84.6% and customers' orders have also been less aligned with their real needs, asking regularly to change the order.

It is worthwhile raising the importance of credit notes related to logistics' issues for two main reasons: (A) direct relation with this dissertation project and (B) high impact on business in a general way. These credit notes were mainly issued because the driver had no time to deliver the orders in the customers' time windows or in the interval of time the driver can legally drive the truck.

The problem is even more noteworthy if we consider other business units. From August 2017 to July 2018, 1124 out of the 2810 credit notes issued at Ferro were related to logistics' issues, in spite of having reduced this cause in 6.7% in this same period of time.

To sum up with, there is actually a logistics problem, which has a negative impact on multiple dimensions. Firstly, it directly threatens the quality of customer service, since there are orders that are not effectively delivered. Secondly, it increases the bureaucracy the administrative structure has to deal with: credit notes, contact with customer, new invoices… And finally, it is costly, because many times it implies unnecessarily labour hours of warehouse workers and kilometres of truck transportation.

The credit note below (see figure 3-1) is a consequence of an order that was not properly delivered because the driver did not have enough time.


Nota de Crédito : NCI/ 18000176

FERRO ENTRONCAMENTO - C.I.F.P.T SA
ZONA INDUSTRIAL NORTE EN 327 KM 27,6 APT.78
3881-901 OVAR
NIPC PT501756710
CRC OVAR
CAPITAL SOCIAL: 610.000,00 EUR

Data : 16-05-2018
Parceiro de negócios : P00005417
Data de vencimento : 16-05-2018
V/ Nr. Contribuinte

Pos. Descrição

Ordem : D00002744 Nr Ordem Cliente
Falta Horário Motorista Fatura 18003905

10 CH.PRETA 3000x1500x3,00 S235JR
EN 10051/EN 10025-2 Peso:

Figure 3-1 - Example of a credit note

3.2 Problems in distribution - causes

The identification of the root cause(s) behind the failures in the distribution process requires a deep comprehension of it. Aiming at obtaining this knowledge about the process, we started by mapping and analysing the process, going from a high-level (see figure 3-2) to a detailed understanding – each phase is extensively described below.

3.2.1 From process modelling and analysis to problem identification

Aiming at obtaining a deep comprehension of the process, we started by mapping and analysing the process, going from a high-level to a detailed understanding, originating the so called AS IS model.

The analysis of a process always starts by modelling the corresponding process. Regarding process modelling, it aims at creating a graphical representation of the process, whereas the process analysis seeks for improvements in its performance (Hunt, 1996).

Concerning the graphic notation, the circles represent the beginning and the end of the process under study: distribution planning and execution. The boxes represent the phases of the process from order entry to order delivery – in some cases, it would be possible to say the process goes from order to cash, but the charge is not important in the scope of this project. The arrows link the phases and the documents represent the output of each phase (Aguillar-Saven, 2004).

Reengineering the process by developing new resources to manage data and support better distribution plans is of great interest. This explores the impact of technology on the efficiency and effectiveness of the process. Moreover, the alignment between workers, technology and the process itself in order to better serve the customers is unquestionably one of the main issues in Services (Bullinger, Fahnrich, & Meiren, 2003).

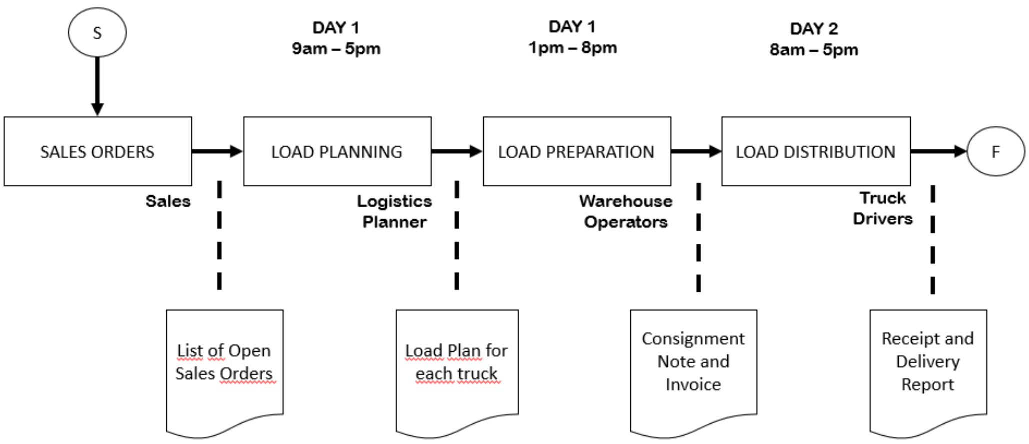


Figure 3-2 - Process Map (AS IS): from distribution planning to execution

3.3 Process description

3.3.1 Sales orders

The external or internal salesman receives a quote request from a customer. If the quote meets the customer's requirements, the order is placed. The internal salesman registers the orders in the ERP, registering product, quantities, place where to unload, date to deliver as well as any other detail seen as important.

Risk 1:

If the sales order is associated with a certain date, the logistics planner may not know the flexibility on the customer side to receive it either earlier or later. Therefore, a certain order may be delivered at an inconvenient day, when in reality the customer enjoyed flexibility to receive it in another date.

Risk 2:

Since the sales order may happen a long time before the invoice day, the salesman may not properly manage the payments to ensure the customer is financially allowed to receive the order at the invoice day – and the order is not actually delivered.

Risk 3:

The logistics manager may integrate a certain order in the daily plan, whose customer has either lack of plafond or due invoices. If an expectable payment does not occur until the order leave the depot, a certain open sale order may be loaded and unloaded when back in depot.

3.3.2 Load planning

The logistics manager prints the open sales orders, which are divided into different geographical areas. Based on this list, he assigns orders to each truck, so he can make a load plan for each truck.

When selecting the orders to be delivered in the following day, the planner takes into consideration the following criteria: lead time agreed, stock availability and financial requirements. When assigning the orders to each truck, the planner takes the following into account: truck capacity in terms of size and weight, address to deliver, time windows, service time and product constraints.

Risk 4:

If the information concerning the order is not duly registered and/or the planner does not check some important details, the load planning may be negatively affected. For instance, the customers may be closed in unexpected days or may have volatile time windows, so it is important to detail information in order to mitigate the risk of loading what cannot be unloaded.

Risk 5:

The planner does not calculate distances among customers, which implies a lack of rigor in the plan setting. The lack of rigor is more remarkable when the number of orders in a truck increases. Therefore, it may not be possible to deliver the orders assigned to a truck.

Risk 6:

Processing all this information is highly complex and requires time, leading to systematic inefficiencies.

3.3.3 Load preparation

The warehouse operators receive the load plan to start preparing the loads, which will be delivered in the following day.

They take the following criteria into consideration, when it comes to preparing the loads: i) distribution sequence - drivers and operators interact - and ii) product features and respective constraints. For instance, flat products are usually transported under long products and products unloaded first should come over the last unloaded.

In the following day at 7am, an Administrative Assistant check all the orders and consequently issues a consignment note and an invoice. These documents cannot be issued in the previous day because the order is likely to be different from what is actually loaded, given the features of the product.

Risk 7:

The load preparation may not be completed in the morning due to lack of time, for instance. On one hand, this leads the driver to leave the warehouse later in the morning. On the other hand, the sequence of visits may be changed in accordance with time windows and/or some orders may not be delivered.

Risk 8:

The Administrative Assistant may verify that the load does not meet the load plan/customer order, which may entail the risk of loading the missing products and/or unloading the unnecessary products as well as readjusting the sequence of visits.

Risk 9:

The Administrative Assistant may not be able to issue an invoice, if the respective customer did not pay past due invoices.

3.3.4 Load distribution

With the due documents and the truck already loaded, the driver can leave.

The driver usually leaves the warehouse between 8am and 9am, following the sequence of visits previously planned, always based on his experience. Drivers seek to minimize the number of kilometers and time, taking into account two main constraints: time windows and load preparation, which results from product features.

Finally, the salesforce and the treasurer ensure the charge is made and the process is finished when the receipt is issued. The charge may occur until some months after the delivery.

Risk 9:

In a long trip with several stops, it is difficult to predict all the details. The route initially planned may not be a good solution if, for example, the driver stays 3 hours stopped when it was expectable to stop only 0.5 hours. The driver redefines the route according to his experience.

Risk 10:

Along the distribution process, the route plan and the changes may not be properly communicated. On one hand, it leads to a weaker service level, since the customer is not properly informed. On the other hand, the truck may take more time to unload, since the customer does not know the arrival time with accuracy and, for this reason, may not be duly organized.

Risk 11:

The occurrence of some of the risks above may lead to (much) higher costs in terms of distribution and fleet.

3.4 Distribution – cost structure

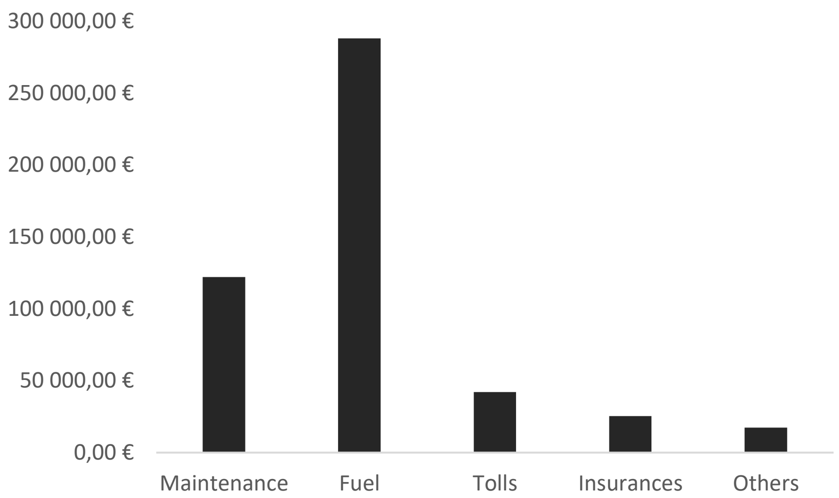


Figure 3-3 - Total costs with heavy fleet from January to August 2018

From January to August, Ferro handled with a cost around five hundred thousand euros with heavy fleet. This cost does not include labour, which was about three hundred and thirty thousand euros for the same period of 2018.

Analysing Figure 3-3, fuel and maintenance represent an important share in the current cost structure. Whereas maintenance weighed 24.7%, fuel weighed 58.21% and tolls only 8.51%. Since all the other costs (insurance, taxes, licences and labour) are fixed costs, it could only be reduced if the fleet dimension suffered changes. Therefore, this dissertation project will be mainly focused on the variable costs.

Taking into consideration these values, we conclude that even a small cost reduction (%) in the heavy fleet may be significant. For instance, a cost reduction of 5% would reduce over forty thousand euros in the last eight months.

Table 3-3 - Cost per kilometre vs per tonne

	Truck	Average (liters)	Reference (liters)	Kms/ton	€/ton
OVAR	A	41,9	40	8,1	4,17 €
	B	41,5	40	8,7	6,89 €
	C	34,1	35	14,1	5,06 €
	D	41,6	40	9,0	5,05 €
	E	30,8	35	15,4	5,99 €

As it can be inferred from table 3-3, in the first six months of 2018, the trucks that need more kilometers to distribute 1 ton are the ones that tend to be more costly. The correlation coefficient between the kilometers per ton and the cost per ton transported is 0.59 for all the trucks, supporting the previous assumption – see appendix A.

For instance, in spite of having the lowest consumption of fuel per kilometer, truck E from Ovar has one of the highest costs per ton transported (€ 5.99). This means the truck travels relatively emptier many kilometers. The number of kilometers needed to distribute 1 ton is 15.4 what is near the double of truck A.

Concerning truck B, it is costly because this truck has implied significant maintenance costs – represented 77.35% of overall maintenance costs in Ovar in the six months under analysis.

3.5 Problem selection

The mitigation of all the risks identified above, which have been behind the failures in the distribution process, would be desirable. However, it would be impossible to cover such a large number of problems in this dissertation project.

Selecting one problem with significant implications in the process and a high independence on the other problems is valuable for itself. Solving such a problem would be an important contribution to improving the process and the whole organization.

For this reason, the abstraction exercise to select the problem was based on the following concerns:

(1) Does the logistics planner have all the data required to build a good distribution plan? Can the logistics planner have a better access to all the important data?

(2) Is there any method to have a faster and/or better distribution plan with the available data?

(3) How can the company improve its service, by reengineering the distribution process?

Taking into consideration these questions and risks identified above, we could come up with a more specific problem. On the one hand, the distances and times among multiple addresses are not accurately taken into consideration. On the other hand, it is highly complex to manage and process all the data required to make good decisions, regarding distribution planning. Solving this problem means taking distances and time into consideration in order to optimize the routes included in the daily distribution plan.

This way the routes will be more accurately calculated, more customers will be served and customer expectations will be more likely fulfilled.

4 Methodology

As already mentioned, this dissertation project follows this sequence: (1) problem identification, (2) requirements gathering, (3) solution study, (4) solution testing and (5) results and gains assessment.

4.1 Problem identification

In Chapter 3, the problem was identified: how can Ferro optimize the distribution of steel products?

The deduction of this question was only possible after having analysed the distribution process, from sale order to order delivery. Afterwards, among the several risks acknowledged along the process analysis, we could come up with one particular problem.

However, primarily, it was crucial to select a problem with the following features: (A) in the scope of our master, (B) with a negative impact on the distribution process, which was the scope defined by Ferro and (C) solvable throughout the short period of time of this project.

4.2 Requirements gathering

At this stage, we should understand the set of requirements that are important to take into consideration in order to solve the problem previously identified and contextualized.

The requirements were collected along with different stakeholders of this process, supported by informal interviews (qualitative research) with drivers, warehouse operators, logistics manager and salesmen. Informal interviews allowed to adapt questions and own conduct to workforce particularities, avoiding biases in their answers and embarrassment (Moeller, Mescher, More, & Shafer, 1980).

However, a structured interview to the drivers was also conducted in order to get objective data (figure 5-6): sequence of visits, kilometres between visits and service time. Data related to orders was directly obtained from respective consignment notes (figure 5 -7).

Finally, an Influence Diagram was built so that we could understand which variables and constraints influence the route planning, whose objective is delivering a set of orders at a minimum cost for the company.

4.2.1 Influence Diagram

According to Howard, & Matheson (2005), managers regularly pass by decision making processes, whose optimal solution depends on different decision alternatives as well as on the state of the world. This process is commonly represented by decision trees, but in this dissertation project the decision process is better reflected by an Influence Diagram (ID), for two main reasons: a) IDs offer a deeper and more compact understanding of the decision problem and b) the application of optimization tools and models is regularly supported by IDs.

Both tools are used to represent uncertain decisions and solve complex decision-making problems. Moreover, both can provide complementary views of a decision problem. On one hand, IDs represent more clearly the dependencies among the variables. On the other hand, the decision trees show more details of possible paths or scenarios.

However, IDs are a much more compact representation, showing the sequential decision and informational structure in a more flexible and clearer way, besides providing a profound understanding of the problem.

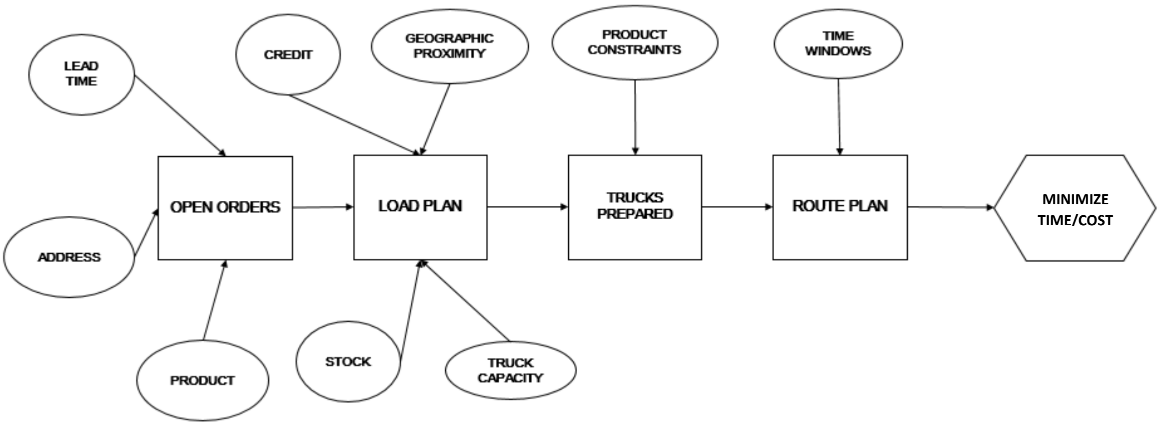


Figure 4-1 - Influence Diagram of Route Planning

In figure 4-1, the arrows denote influence, circles represent general variables, squares represent decisions to be made and the hexagon represents the decision's objective.

According to this influence diagram, minimizing the time and costs related to the routes of distribution depends on a large set of variables which have their influence in different stages of the process.

- The logistics planner has access to the following data, which comes with the sales order: (1) lead time, (2) address where the order has to be delivered to and (3) quantities and specifications of the products.

- The selection of the open orders to be delivered in the following day depends on: (4) the existence of stock, (5) the customer meeting the credit requirements, (6) geographic proximity to other orders to be delivered and (7) truck capacity.

- The trucks are prepared by the warehouse operators, taking into account some product constraints: plates under tubes, for instance.

- With the truck already loaded, the drivers set a distribution route being aware of time windows and how the products are disposed/ordered in the truck.

4.3 Solution study

Integrating this large set of variables and constraints would be highly complex to model mathematically. More importantly, in the current context, lack of stability among these variables and constraints would make such a complex model useless. The lack of stability is due to the fact that the order may change until the very last minute, the expected payment may not occur, or the workers may not load the truck in the expected time, among other motives.

Otherwise, if all the information were stable when planning the routes, a complex model could actually optimize all the routes, taking into consideration all the data above. However, the routes would be optimized based on only temporarily true information. Any change could have an impact on the set of routes planned, when steel is heavy and takes a long time to change from a truck to another. Moreover, if the changes occur when the trucks are already on the road, any change in the loads is impossible.

For this reason, we decided to divide the problem in two different parts, requiring two different solutions:

- Manage the information to assign the orders to each truck;
- Optimize the routes, knowing the orders that will be delivered by each truck;

4.3.1 Google MyMaps

The first problem will be addressed with a geographic decision support system, developed with Google MyMaps. This tool is based on the Google Maps platform, allowing a freely personalization of maps, as well as the import of data from Excel files, for instance.

The use of Google MyMaps and its integration in the current distribution planning process will be explained in the following chapter. The customization of maps will improve the visualization of data, as well as quickly calculate distances and times between multiple addresses.

4.3.2 VRPTW

Regarding the second problem, each route will be optimized by solving the identified vehicle routing problem with time windows (VRPTW) and product constraints, formulated as a linear programming problem.

The problem is studied in the literature and in this dissertation we will adapt the mathematical formulation of Toth and Vigo (2001).

<u>Customers</u>

A set of customers $N = \{1, 2, \dots, n\}$ reside at n different locations. Every pair of locations (i, j), where $i, j \in N$ and $i \neq j$ has associated a travel time t_{ij} and a distance traveled D_{ij} that are symmetrical. We designate by q_i the demand at point i and assume that the central depot is represented by 0.

Vehicle

The customers are served from one depot with a vehicle belonging to a standardized and limited fleet. The vehicle leaves and returns to the depot. The capacity of the vehicle is represented by a.

We let ri = {ri (1), …, ri (n)} designate the route of the vehicle, where ri(j) is the index of the j^{th} customer visited and n is the number of customers in the route. We assume that every route finishes at the depot.

Time windows

Each customer $i \in N$ has a time window, an interval [ei, li], where $ei \leq li$, which corresponds, respectively, to the earliest and latest time to start serving customer i. si is the service time of customer i.

The decision variables of the model are:

Xij = 1, if j is supplied after i;

0, otherwise

bi = moment at which service begins at customer i, i = 1,…, n; k = 1,…, m

The objective function can be written as follows:

$\text{Min} \sum i \in [0, n] * \sum j \in [0, n] * Dij\ Xij$

The model constraints are:

1. $\sum j \in [1, n] * X0j = 1$
   Constraint 1 guarantees that the vehicle will leave the depot and arrive at a determined customer.

2. $\sum i \in [0, n] * Xip - \sum j \in [0, n]\ Xpj = 0, p = 0, ..., n$
   Constraint 2 is about entrance and exit flows, and guarantees that each vehicle will leave a determined customer and arrive back to the depot.

3. $bi + si + tij – Mij\ (1 – Xij) \leq bj \quad i = 1,…, n; j = 1,..., n$
   Equation 3 sets a minimum time for beginning the service of customer j in a determined route and also guarantees that there will be no sub tours. The constant Mij is a large enough number, for instance, Mij = li + tij – ej

4. $ei \leq bi \leq li \quad i = 1,…, n$
   Constraint 4 guarantees that all customers will be served within their time windows.

5. $Xij \in \{0, 1\} \quad i = 0,…, n; j = 0,…, n;$
   Constraint 5 guarantees the decision variables Xij to be binary.

In spite of having been developed in Ovar, this project takes advantage of data from other business units to have access to more robust information and shape better conclusions. In Appendix A, important additional knowledge regarding the problem under study is presented in detail, which needs to be somehow addressed in our model.

Steel is a heavy product and the weight transported has a significant impact on the fuel consumption of any truck. Consequently, one kilometre of an empty truck is obviously much cheaper than 1 kilometre of a truck with orders to be delivered.

The previous formulation does not distinguish a route for which the nearest customer is the first to be served from the reverse route for which the most distant is the first to be served, since the kilometers and traveling time are expected to be the same. In fact, even if the truck has to travel more kilometers, it may be preferable to unload a relatively heavier order.

With this argument emerges a trade-off difficult to manage and accommodate in a model: the effect on costs of kilometers traveled versus effect on costs of weight transported. In fact, theoretically, we could analyze the effect of kilometers and weight on the fuel consumption of each truck. However, it is difficult to accurately measure without considerably interfering in the daily operations of Ferro. For this reason, our model will not accurately accommodate this trade-off, but will take into account the decisions of logistics planners regarding this issue as follows.

According to the previous argument, one kilometer of a truck emptier is cheaper. Therefore, along the road, the average of weight carried should be as low as possible in order to minimize transportation costs.

To simplify, addressing this issue, the logistics planner will be able to set the first visit or any other. Since ri = {ri (1),…,ri (n)} denotes the route and ri(j) is the index of the j^{th} customer visited and n is the number of customers in the route, the logistics planner should set ri(j) with the intended index.

Another motivation to allow the logistics planner to set indexes is the need to address specific requirements related to the features of the steel products. For instance, the long products should travel above the flat products, which means that the long products should be unloaded first in order to enable the unloading of the flat products.

4.4 Solution testing

These two tools were tested in parallel to avoid interfering in the daily job of the logistics planner. We tried to reproduce the real context of route planning in order to reach valuable conclusions. For this reason, this research is based on the same data that supports everyday decisions.

The research and conclusions were widely shared with the logistics planner and logistics controller to ensure the validity of the assumptions and conclusions. Their feedback and continuous validation were essential to build these two solutions.

4.5 Results and gains assessment

The assessment of the results and gains obtained with these two tools will be introduced by comparing routes actually followed by the drivers and routes recommended by our model.

These two tools will be firstly tested to confirm their ability to solve the identified problem, regardless of the context of application. Afterwards, having understood how these two tools can be used, as well as the value both can bring to distribution planning at Ferro, routes will be optimized based on data from the operational reality of Ferro.

Two practical examples will be analysed to better understand the virtues of our tools. Expected gains will be assessed based on the comparison between routes calculated with and without the application of these tools.

5 Results

In this chapter, the proposed solution will be presented in further detail, as well as the gains that may result from the implementation of the following two tools in the current distribution process:

- A data visualization tool developed with the support of Google MyMaps, whose goal is to ensure all the relevant data is available in a user-friendly way, so that the logistics planner can make a more efficient and effective allocation of the orders to each truck;
- A route optimizer based on Excel Solver, linked to Google Maps, in order to obtain optimal solutions to deliver the set of orders allocated to each truck by taking into consideration the times between multiple points of delivery;

Figure 5-1 illustrates how the two tools are harmoniously integrated in the initial distribution process, but understanding the detail of each solution is essential to better understand the full potential of this TO BE version of the process. For this reason, this chapter is divided in two parts: (1) load planning with Google MyMaps and (2) load distribution with Excel Solver, which is the main focus of this dissertation project.

Afterwards, two practical examples will be discussed and a set of advantages of implementing these two tools will be identified and explained.

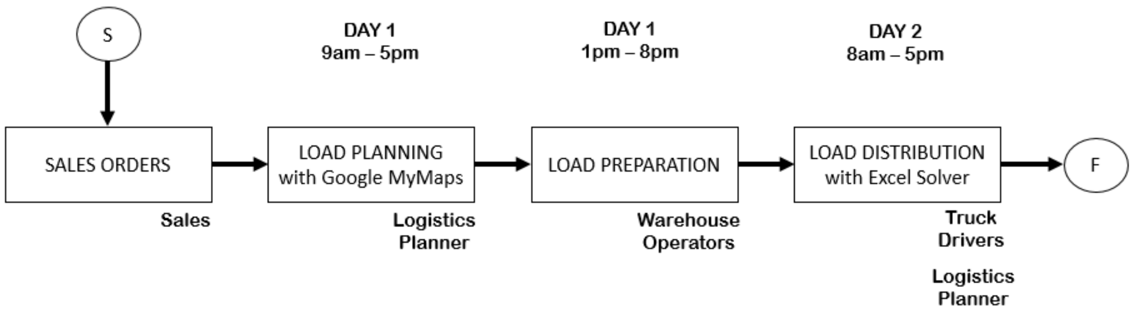


Figure 5-1 - Process Map (TO-BE): from distribution planning to execution

5.1 Load Planning

Currently, the logistics planner organizes the data that results from sales orders in an Excel file - see figure 1-2 -, in order to decide which orders will be delivered in the following day and which truck will carry each order.

As we can realize, distances and times between points of delivery correspond to the perception the planner may have. It means that in this specific decision the objective is to join orders to be delivered in two or three close towns. However, for instance, with this method the planner is not able to plan in order to distribute along the way, when unloading part of the weight transported close to the depot would significantly reduce the transportation costs – see figure 5-8.

5.1.1 Load Planning (TO BE)

It is important to understand the integration of Google MyMaps in the current process. Infor LN, which is Ferro's ERP, allows exporting a list of sales orders to Excel, with the following fields: customer, street, zip code, town and weight of the order. Moreover, more data can be added to this list, if it is understood that it may improve load planning.

Additionally, Google MyMaps allows importing addresses from multiple columns in Excel and turn them into points in a map. This set of points may have different colours and symbols according to the criteria that are set, e.g. (A) addresses may be linked to a region, which may benefit from each region having a different colour; (B) each order is associated to a lead time, which may have a different symbol; (C) each order has a weight and each weight may be inserted in an interval, which may be associated to a different colour (see figure 5-2). These different criteria only have to be selected, providing different perspectives in a few seconds.

Furthermore, each point may have a related comment/box, which may be imported from one column in Excel, e.g. local constraints to unload, special transport required, customer means to unload and financial situation. These comments are a useful function to add text with importance to making good logistics decisions.

However, the most important function is the ability for the planner to connect multiple orders and estimate route time and distance, as well as understand the possibility of connecting multiple orders from multiple towns (see figure 5-3). Therefore, this tool allows designing a geographical plan which may be compared with the actual route observed in the tracking system.

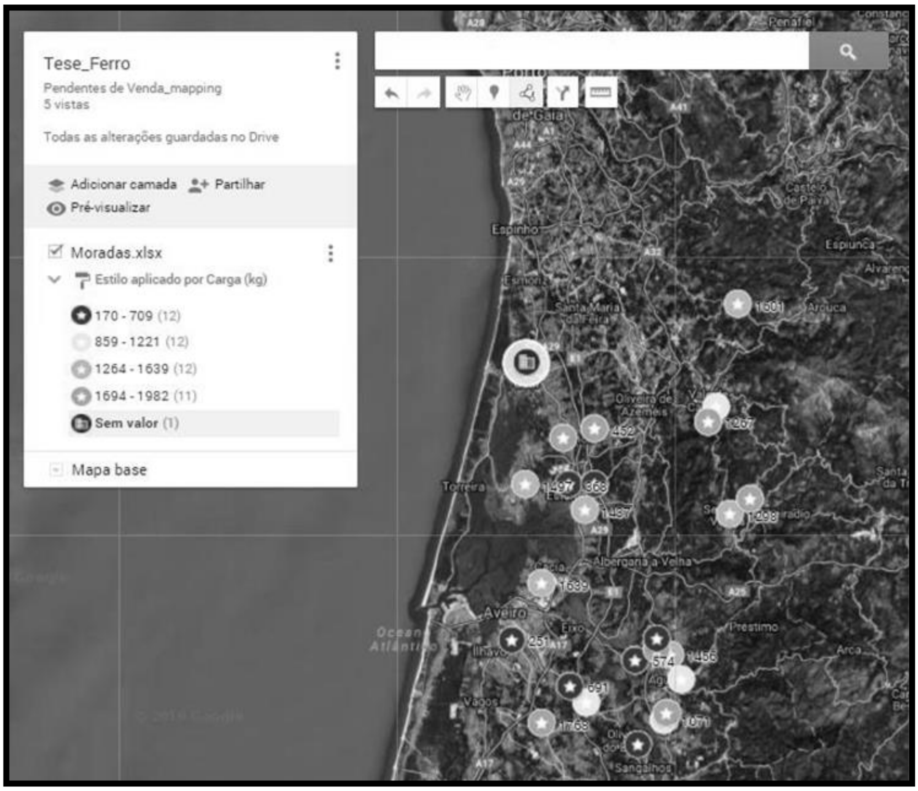


Figure 5-2 - Pending orders from Ovar at Google MyMaps

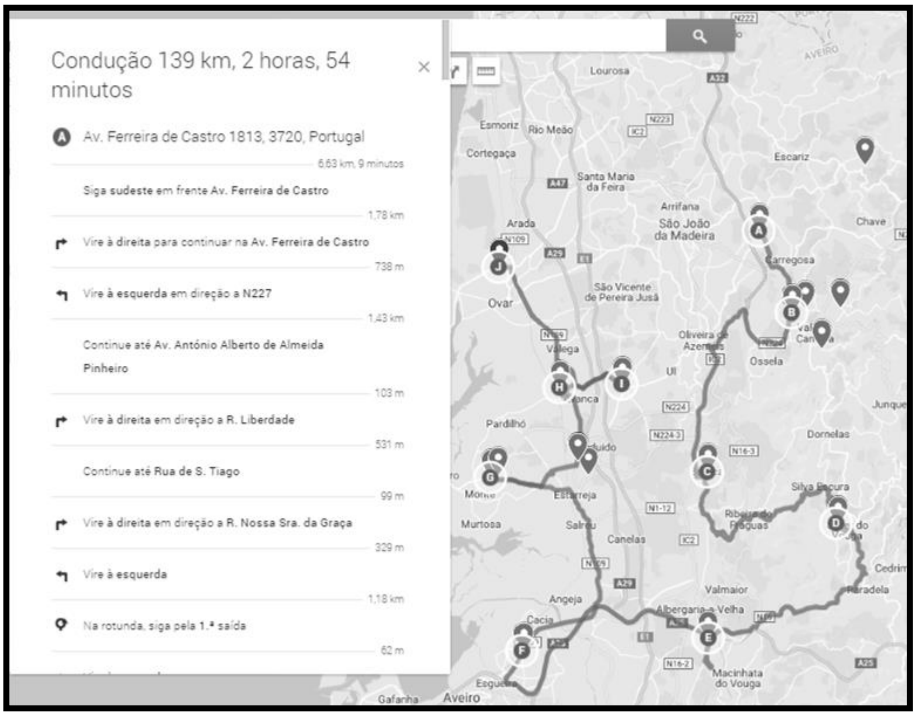


Figure 5-3 - Estimated route distance and time with Google MyMaps

In summary, this tool would help the planner better manage all the relevant data when it comes for allocating orders to each truck. Taking explicitly into consideration estimates for time and distance and having a data visualization system is undoubtedly an important improvement to this process.

In some cases, the use of Google MyMaps can assist in providing good solutions to our problem, even without the support of our optimization module.

5.1 Load Distribution

As previously mentioned, optimizing the distribution of steel products is the main goal of this dissertation project. However, the geographical visualization of data may be an important complement to the mathematical optimization component. The visual experience makes the optimization tool conclusions more easily understood, since Google MyMaps allows the planner to design/map the optimization tool solution.

Currently, the definition of routes is highly dependent on the experience of the drivers. The route is defined by the drivers according to some constraints the planner shares with them. Moreover, drivers do not count on GPS to help choosing and following the best route and the logistics planner does not properly control the route – the tracking system is still under development.

5.1.1 Load Distribution (TO-BE)

It would be desirable to make logistics more autonomous by counting on mathematical optimization. In a best scenario, the model we are developing would turn sales orders into distribution routes. However, the processes that have an impact on the distribution process are still not stable and such an ambitious model could be calculating routes based on erroneous assumptions. Thus, it was decided to give a first step at Ferro in the area of optimization by selecting a context whose assumptions would be stable and the output would be valid.

The expected gains with this component are highly dependent on implementation and integration in the existing process. Therefore, the use of the optimization module in this dissertation project will firstly be explained. The explanation will be based on a simple example. Afterwards, we will assess the results based on practical examples.

In Table 5-1, all the destinations are presented with their respective time windows (earliest start and latest finish), service time and address. This table brings together key parameters to obtain an optimal solution for the route of a specific truck.

Table 5-1 - Time windows, service time and addresses

Stop	Earliest Start	Latest Finish	Service	Address
FERRO OVAR				Avenida D. Manuel 1, Ovar
Customer B	150	300	30	Rua 1º de Maio, Santa Maria da Feira
Customer C	0	200	40	Largo José Guilherme de Sousa, Arco de Baúlhe
Customer D	0	300	50	Rua do Vilar, Porto

Table 5-2 - Time (in minutes) between all stops

	FERRO OVAR	B	C	D
FERRO OVAR	0	15	79	32
Customer B		0	70	26
Customer C			0	61
Customer D				0

Taking into consideration the addresses, it is possible to directly calculate the distance and time between two destinations by using an API of Google Maps. The times that separate the depot and three randomly selected customers are presented (see table 5-2).

The last and following tables could be generalized to another with ten or even more customers/stops.

Finally, Excel Solver can obtain the route that takes the minimum time to deliver all the orders within the respective time windows, taking into consideration travelling times and service times (see figure 5-4).

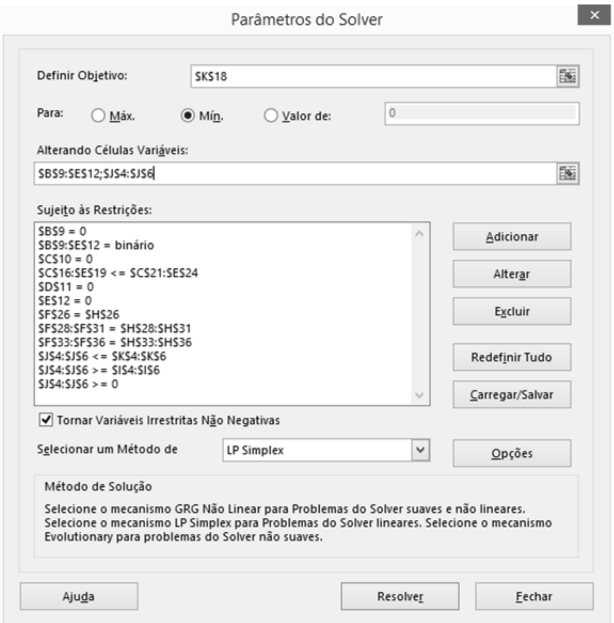


Figure 5-4 - Excel implementation of the VRPTW

0	1	0	0
0	0	1	0
0	0	0	1
1	0	0	0

Sequence	Time
FERRO OVAR	0
D	32
C	143
B	253
FERRO OVAR	298

Figure 5-5 - Sequence of destinations

The output comes in the form of a binary table, whose meaning is better understood with a filter ordering the stops in accordance with the times calculated by the optimization tool (see figure 5-5).

In the special case of an order that had to be firstly delivered, a new constraint had to be added: “order D delivered First”.

5.2 Gains

Accurately assessing the gains of implementing our geographical decision support system and optimization module is difficult. Firstly, testing in parallel both scenarios, with and without an optimization tool, and therefore comparing the results of the logistics planner’s decisions with those developed in this dissertation project is not correct, since our problem is dynamic/mutable and the results of our decisions depend on the results of future decisions. Secondly, even if we had the chance to truly implement these two tools and actually support route decisions in this new system, it would be difficult to correctly compare two different periods of time, because the assumptions of our problem change with time.

In fact, coming up with a measure to fairly and precisely assess the value of this dissertation project is difficult. However, it does not mean we cannot objectively point out some of the gains and virtues of our research throughout the last seven months. Hence, twenty seven routes will be analyzed.

5.2.1 Practical examples

After having decided to focus on tackling the VRP of Ferro, routes from Ovar were analyzed to better understand the problem. Two routes will be analyzed in further detail in order to better understand the virtues and limitations of the two models here developed.

<u>Example 1</u>

The first example is based on figures 5-6, 5-7 and 5-8.

Renato Miguel Oliveira **Ferro**

De: Guilherme Sousa
Enviado: domingo, 29 de abril de 2018 11:17
Para: Renato Miguel Oliveira
Assunto: Pedido a motoristas

Bom dia Renato,

Vou pedir-lhe que na próxima quarta os motoristas registem o percurso, cliente a cliente, tempos de viagem e kms entre cada cliente, por forma a poder fazer uma análise comparativa com o modelo que estou a desenvolver.

Agradeço-lhe.

Cumprimentos,
Guilherme

Enviado do meu telefone Huawei.

DE:
— ANTONIO COUTO SILVA
— VIATURA - 37-TA-15 - AV-56059
— FERROMAR — SAÍDA - 08:17 HORAS — CHEGADA - 19:12 — KM 25 911 / 25.742 = 169
— CHEGADA - 09:08 HORAS / SAÍDA - 09:05 H — KM - 25 742 / 25 777 = 065
— CHEGADA - 09:15 H / SAÍDA - 10:00 — KM - 25780 / 25777 = 03
— CHEGADA - 10:08 H / SAÍDA - 10:36 — KM 25 784 / 25 780 = 04
— CHEGADA - 10:59 H / SAÍDA - 11:39 — KM 25790 / 25784 = 06
— ÍDA CHEGADA - 11:55 H / SAÍDA - 12:16 — KM 25796 / 25790 = 06
— CHEGADA - 13:09 / SAÍDA - 17:36 — KM 25.857 / 25 796 = 061

Figure 5-6 - Data collection: route sequence, kilometres and time

Ferromar — **Cargas Efectuadas por Matrícula** — 01-09-2018 18:04

02-05-2018 00:00 <> 02-05-2018 23:59

Matrícula	Carga	Parceiro	Artigo	Quantidade	Peso - ton
37-TA-15	C20044698		VARÃO RED. 12 MM C/6 MTS.	1 426	1,426
		TOTAL PARCEIRO		1 426	1,426
		TOTAL CARGA	C20044698	1 426	1,426
		TOTAL FACTURA	**FTA/ 18003457**	**1 426**	**1,426**
	C20044700		BARRA RECT.300x15 MM C/6 MTS.	216	0,216
			PERFIL IPE 200 MM C/ 6,00 MT	2 733	2,733
		TOTAL PARCEIRO		2 949	2,949
		TOTAL CARGA	C20044700	2 949	2,949
		TOTAL FACTURA	**FTA/ 18003458**	**2 949**	**2,949**
	C20044672		BARRA RECT. 50x 6 MM C/6 MTS.	43	0,043
		TOTAL PARCEIRO		43	0,043
		TOTAL CARGA	C20044672	43	0,043
		TOTAL FACTURA	**FTA/ 18003459**	**43**	**0,043**
			CH.PRETA 3000x1500x10,0 S235JR	1 800	1,8
			PERFIL UPN 140 MM C/12 MTS.	968	0,968
		TOTAL PARCEIRO		2 768	2,768
		TOTAL CARGA	C20044672	2 768	2,768
		TOTAL FACTURA	**FTA/ 18003460**	**2 768**	**2,768**
			PERFIL HEA 240 MM C/12 MTS.	730	0,73
			PERFIL IPE 220 MM C/12 MTS.	952	0,952
			PERFIL IPE 240 MM C/ 6,00 MT	187	0,187
			PERFIL IPE 240 MM C/12 MTS.	2 972	2,972
			TUBO W 76.1x3.60 (2.1/2") MP	12	0,077
		TOTAL PARCEIRO		4 853	4,918
		TOTAL CARGA	C20044672	4 853	4,918
		TOTAL FACTURA	**FTA/ 18003461**	**4 853**	**4,918**
			TUBO QUAD 100,0 x 5,00 S275J0H	600	8,646
		TOTAL PARCEIRO		600	8,646
		TOTAL CARGA	C20044672	600	8,646
		TOTAL FACTURA	**FTA/ 18003462**	**600**	**8,646**
		TOTAL MATRÍCULA	37-TA-15	12 639	20,750

Figure 5-7- Data collection: product features and weights

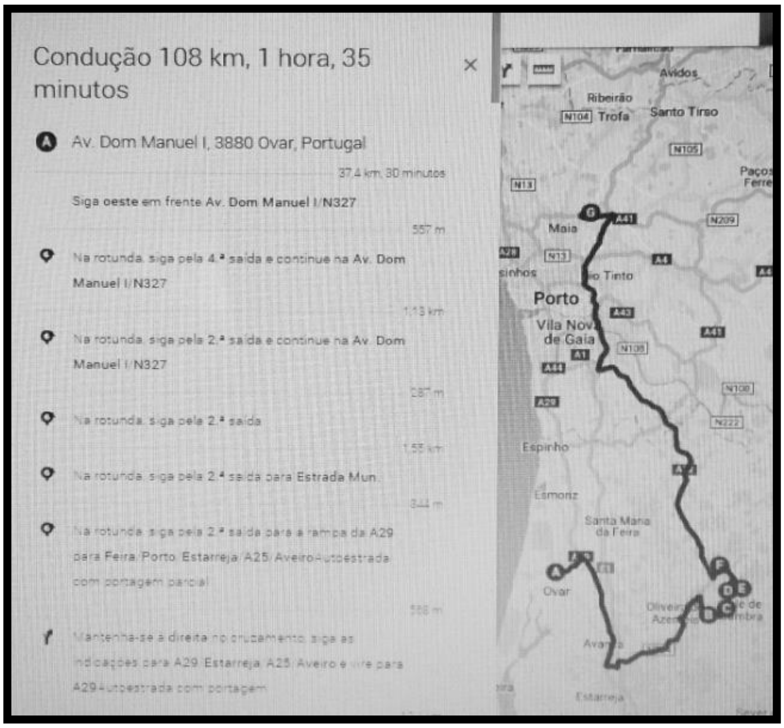


Figure 5-8 - Optimized routes

In figure 5-6, the route actually followed by a driver in May 2nd is given. That day, the driver visited six customers before getting back to Ovar and drove 115 kilometers from Ferro Ovar to destination "G" – see figure 5-8. According to figure 5-7, over 20 tons were distributed that day and the heaviest order (8.65 tons) was the second to be unloaded. Finally, in figure 5-8, the optimized route corresponds to 108 kilometers, visiting first destination "D" and then "E" – this route is 6,1% shorter than the one chosen by the driver. Note that "G" had to be the 6th visit.

Although there is a difference of 7 kilometers between these two routes, it is important to raise the fact that Google Maps assumes that trucks and cars can be driven in the same roads, when there are roads that cannot be driven by trucks. Moreover, it may have happened that the order of "E" was over the order of "D" and therefore the driver had to firstly stop at "E". However, if we analyze the orders/product features, it would actually be avoidable and the sequence could be the one calculated by the optimizer.

<u>Example 2</u>

The second example intends to better expose the limitations of Google MyMaps and the implemented optimization model.

In this example, the driver had to deliver twelve orders on September 3rd - twice the previous example. As can be seen in figure 5-9, the driver goes from A to B and gets back towards A to visit C, D, E and F. Apparently, this is inefficient and would be avoidable, because the driver drove 58 kilometers when in the optimized route the driver would only drive 41 kilometers – less 29.3%. Analyzing the consignment note, we can conclude that the driver went firstly to B to unload tubes with 6 meters.

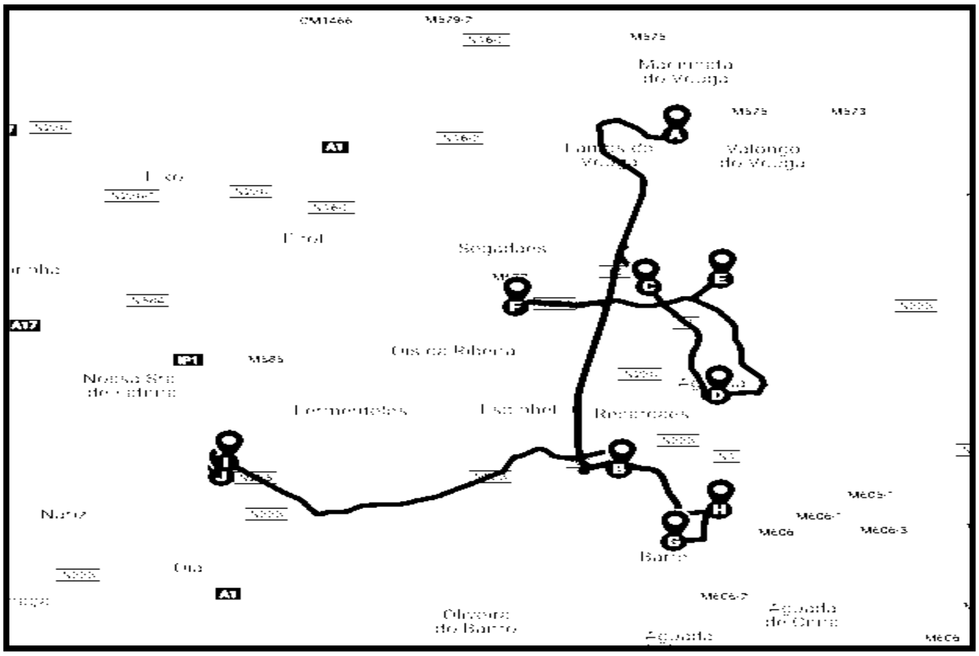


Figure 5-9 - Route chosen by the driver: from A to J

In this same figure, we can notice that three addresses out of thirteen were not mapped. When testing some of the routes analyzed, it was observed that Google MyMaps can only integrate until ten addresses in any route calculation, which means that only nine customers can be processed.

In spite of being undoubtedly a limitation, this hurdle can be overcome by turning the actual problem into a problem with less addresses. Most of the times, there are addresses we know that will be the first or the last to be served – the problem lies usually in the middle of the sequence. Regardless of this limitation, Google MyMaps is a powerful tool. Among all the route tests we had the opportunity to conduct, every address was identified/recognized and accurately represented. Moreover, the number of orders that can be represented on Google MyMaps is limitless, so the whole load map can be reflected by this tool.

It was also experimented that Excel Solver, in its standard version, can only calculate routes with up to eight addresses/seven customers, since it can only process until 100 constraints and 200 variables. Our mathematical formulation has five types of constraints. For instance, constraint type 5 guarantees the decision variables Xij to be binary and constraint 4 that all customers will be served within their time windows. This means that with eight orders, there will be 81 (9 addresses x 9 addresses) binary decision variables and 16 [8 customers x (earliest time to serve + latest time to serve)] constraints related to time windows, so 100 constraints would not be enough to accommodate this instance.

However, it is easy and cheap to implement this same model in a more capable Solver, as far as the number of constraints and variables is concerned.

Although most of the routes can be supported by these two tools, there are usually routes with over seven customers. More importantly, the more customers the trucks have to visit, the more useful these tools would become, because the VRP tends to be more complex with the number of customers.

Taking into consideration the sample collected, trucks leave the Ovar warehouse with 5.7 orders to be delivered, on average. Moreover, the median and mode were 6 orders, with a minimum of 1 order and a maximum of 12 orders. This means that in some of the routes we had to transform the problem in order to obtain an answer from our model.

In this case, this limitation may be surpassed by (1) reformulating the model in order to reduce the number of constraints or (2) implement this same formulation in a more capable software solution. Regarding alternative (1), time windows are very often flexible and therefore these constraints can be added when strictly necessary. When it comes to alternative (2), the assessment of alternative optimizers is out of the scope of this project. Excel Solver was selected because it has not only the advantage of being integrated in a tool daily used in the company, but also because it is legally free of charge.

5.2.2 Expected benefits

Identifying the limitations of these two tools is fundamental to open the pathway that the company under study may follow in order to keep improving the distribution of steel products. However, the development of these two tools already represents a significant advance in terms of distribution planning.

Among the twenty seven distribution routes analysed, the results of the optimizer allowed theoretically to reduce over 5% the number of kilometres, on average. For instance, from January to August 2018, Ferro supported a total cost with the fleet of around eight hundred and thirty thousand euros, including labor. Thus, a cost saving of 5% with fleet would lead to a reduction of around forty-one thousand and five hundred euros in this period of time.

For the company, the tangible gains of this dissertation lie both in the knowledge acquired related to heavy fleet in broader terms and distribution planning in specific and the tool development side of this dissertation was also fruitful, since the two tools here developed and explained already promise to lower operational costs and serve customers better and faster. Moreover, these tools allow controlling the daily decisions of drivers and measuring their performance, which is decisive to keep improving a process that is crucial for this industry.

6. Conclusion

In this chapter of conclusion, we look back to the purpose of this project to understand in retrospective how our object of research is aligned with the results that were obtained. Additional opportunities for future work are also identified.

This conclusion follows a time logic: past, present and future. This sequence helps us understand the problem and respective answers in a cross-cutting way, always with an objective: keep finding better solutions for an existing problem.

6.1 Relevance of this project

To better summarize the relevance of this project and the motivation to undertake it, we focus on four main ideas:

6.1.1 Business processes

The high dependence on the drivers' experience to "calculate" the routes was realized throughout this period of time. For instance, in Ovar the five drivers work in the company for 14.8 years on average. However, the labor market is getting more and more dynamic, with the employees spending less and less time in a same company. This point means that even if route planning is consistently near-optimal at the moment, that may be explained by the accumulated experience of current workers. Furthermore, the company is engaging with several new customers/addresses, which my lead to route inefficiencies if Ferro keeps relying only on drivers' knowledge.

The former CEO of Toyota Motor Corporation, Katsuaki Watanabe, said once that Toyota gets "brilliant results from average people managing brilliant processes", which means that results depend much more on the business processes than on people capabilities.

6.1.2 Digitization

It was observed the existence of routes with millions of different possible combinations. For example, routes with ten deliveries lead to 3 628 800 alternative routes. The best route is the least costly, without compromising the delivery of all the orders. Constraints such as time windows, service time and product features may reduce the alternative routes but make the problem even more complex.

As we have observed, this problem is mainly addressed by the logistics planner and drivers with the support of Excel and many sheets. Fortunately, there is technology to solve such a difficult problem with expected high productivity gains.

Furthermore, obtaining a fast and accurate route plan leads to less errors and better communication among all the stakeholders of this process and consequently to gains of productivity. For instance, credit notes whose cause is related to logistics are a consequence of all the errors throughout the distribution process, leading to additional and unnecessary administrative work.

6.1.3 Define, Measure, Analyze, Improve and Control

The important role played by the drivers in the distribution process is unquestionable. Therefore, for a company that adds value by retailing steel products, it is crucial to "control" drivers and routes in order to constantly "define" the problems along the process. Whereas a tracking system allows to follow the route, the optimization module allows obtaining an optimized route/plan to "measure" and compare with the route actually followed by the driver. Decisions along the route must be "analyzed" in order to continuously "improve".

6.1.4 Customer focus

In such a competitive industry, customer service is the factor that more distinguishes companies. Effectively delivering the orders to customers within the due lead time is vital, so the company has to efficiently ensure the distribution of the orders the salesforce committed to deliver. Moreover, tracking the orders and previewing the delivery time is important for increasingly strict customers. Technological tools allow real-time answers as well as better alignment and communication between salesforce and customers.

6.2 Main results

Regarding added value to the company, as it has been raised, this research project had the virtue of having collected a large amount of data and turning it into knowledge with implications on daily decisions. Today, for instance, each truck is linked to a cost per ton delivered, as well as a number of kilometers to distribute one ton. Moreover, the cost structure of each truck is detailed from insurance and fines to fuel, tolls and maintenance. This is important to control not only the performance of each truck, but also of each driver.

Furthermore, the detailed level of understanding of the distribution planning allowed to identify a set of problems that the company will have to properly manage in order to improve outbound logistics. The evolution in the departure time of the drivers in Ovar, which is a good business unit from this point of view, is illustrative of the difficulties that challenge the output of this process. Additionally, the credit notes related to drivers' lack of time are also a symptom of the problems identified.

Finally, after having studied the distribution planning, it was possible to define a more specific scope for this dissertation project: optimization of routes in the distribution of steel products. Supported by an influence diagram, it was understood in further detail the impact of each variable and constraint in distribution performance. The features of steel products and the need to deliver orders within time windows justify the mathematical formulation that was used, as well as the title of this dissertation.

As an attempt to avoid dealing with all the problems related to distribution, it was decided to use a formulation that would optimize each truck route. However, since this optimization firstly depends on order allocation, we imagined and then took advantage of an existing tool to support this first decision. Whereas the optimizer promises to reduce costs with heavy fleet in at least 5%, the geographical decision support system already had spillovers in the organization, thanks to its ability to visually organize any kind of data linked to maps.

6.3 Future work

6.3.1 Implementation

When it comes to future opportunities of research, most immediate one is: implementing the two tools here developed, as well as measurement of the distribution process outputs post-implementation. In fact, the period of time of this dissertation represented a constraint and in spite of having tested the tools and validated the results, the implementation phase was beyond the scope of the time and effort of this dissertation. Therefore, studying in detail the implementation of both tools and respective measurement is required.

Regarding implementation, there is a particular concern to be raised: the obstacle set by (cultural) change aversion. This study has the ambition of trusting computers to perform what people have executed for many years, which implies a great change on internal culture. The success of this project will not only depend on the development of software solutions for a real problem, but also on the involvement of a large set of stakeholder. This involvement and consequent change requires time and “political capital”.

6.3.2 Different levels of optimization

When processed by Excel Solver in its standard version, the model formulation here explained does not properly address instances with eight or more customers. A more capable software solution or a more efficient mathematical formulation is necessary to make it effective regardless of the number of customers.

In this project, the mathematical formulation only allowed to optimize the route of each truck. However, there are at least two higher levels of optimization that could lead the company to an upper stage in terms of efficiency, as far as outbound logistics is concerned.

- Warehouse level: the truck routes may be all optimized, depending on the ability to collect relevant data when planning the routes.
- National level: currently, the area of distribution overlaps the commercial area of each warehouse. However, synergies in distribution among the six warehouses may be assessed in order to place centralization of logistics as an alternative to local planning.

6.3.3 Externalization of logistics

In 1981, when the company decided to deliver steel products from warehouse to customers with proprietary fleet, it was an impactful strategic decision with long term consequences. Regarding the future, with the specialization of logistic companies in a low margin business, the externalization of transportation may be assessed.

Appendix

	Truck	Average (liters)	Reference (liters)	Kms/ton	€/ton
OVAR	A	41,9	40	8,1	4,17 €
	B	41,5	40	8,7	6,89 €
	C	34,1	35	14,1	5,06 €
	D	41,6	40	9,0	5,05 €
	E	30,8	35	15,4	5,99 €
BRAGA	F	35,3	35	20,6	14,05 €
	G	37,5	35	19,7	10,56 €
	H	38,5	35	18,0	9,22 €
	I	41,3	40	11,9	7,12 €
	J	36,7	35	18,0	12,02 €
SETÚBAL	K	32,8	35	19,7	21,64 €
	L	40,9	40	7,8	4,89 €
	M	37,9	35	20,1	15,75 €
	N	32,4	35	20,7	21,53 €
	O	36,5	40	11,2	5,84 €
MANGUALDE	P	33,3	30	17,1	7,07 €
	Q	37,3	40	12,5	6,59 €
	R	30,7	35	22,0	9,24 €
	S	31,5	30	26,9	9,63 €
ENTRONCAMENTO	T	36,9	35	23,6	10,60 €
	U	41,4	40	12,5	8,92 €
	V	40,3	40	11,2	5,83 €
	X	35,8	35	19,9	11,79 €
	Y	31,3	35	24,7	9,79 €
PORTIMÃO	Z	29,7	40	25,2	10,60 €

Appendix A – Cost of distribution per kilometre and tonne for each truck

References

Aguilar-Saven, R. S. (2004). Business process modelling: Review and framework. *International Journal of production economics*, *90*(2), 129-149.

Back, T., Hammel, U., & Schwefel, H. P. (1997). Evolutionary computation: Comments on the history and current state. *IEEE transactions on Evolutionary Computation*, *1*(1), 3-17.

BBC (2018). Retrieved from https://www.bbc.com/news/world-us-canada-44320221

Bullinger, H. J., Fähnrich, K. P., & Meiren, T. (2003). Service engineering—methodical development of new service products. *International Journal of Production Economics*, *85*(3), 275-287.

Carić, T., Pašagić, S., & Lanović, Z. (2004). Vehicle Routing Problem Models. *PROMET-Traffic & Transportation*, *16*(1), 59-62

Cheng, Y., Liang, B. & Zhou, M. J. Cent. South Univ. Technol. (2010) 17: 873. Retrieved from https://doi.org/10.1007/s11771-010-0570-9

Conte, S. D., & De Boor, C. (2017). *Elementary numerical analysis: an algorithmic approach* (Vol. 78). SIAM.

Cooper, M. C., Lambert, D. M., & Pagh, J. D. (1997). Supply chain management: more than a new name for logistics. *The international journal of logistics management*, *8*(1), 1-14.

Cordeau, J. F., Laporte, G., & Mercier, A. (2001). A unified tabu search heuristic for vehicle routing problems with time windows. *Journal of the Operational research society*, *52*(8), 928-936.

Desrochers, M., Desrosiers, J., & Solomon, M. (1992). A new optimization algorithm for the vehicle routing problem with time windows. *Operations research*, *40*(2), 342-354.

Diamond, J. M. (1998). *Guns, germs and steel: a short history of everybody for the last 13,000 years*. Random House.

European Comission. (2018). *Comission imposes definitive anti-dumping duties on Chinese corrosion resistant steel.* Retrieved from http://trade.ec.europa.eu/doclib/press/index.cfm?id=1794

European Steel Association. (2018, May 31). *Importance of transport for the European steel industry*. Retrieved from http://www.eurofer.org/Issues%26Positions/Transport/Events/Transport.fhtml

European Steel Association. (2017). *Economic and steel market outlook*. Retrieved from http://www.eurofer.org/News&Events/Press%20releases/ws.res/Market%20Outlook%20Quarter%201%202018.fhtml/20180206%20ECONOMIC%20REPORT%20-%20Quarter%201%202018-vFINAL.pdf

Ernst & Young. (2018 May 31). Volatile times call for bold decisions by steelmakers. Retrieved from http://www.ey.com/gl/en/industries/mining---metals/the-steel-hub

Fu, L. L., Aloulou, M. A., & Triki, C. (2017). Integrated production scheduling and vehicle routing problem with job splitting and delivery time windows. *International Journal of Production Research*, 1-16.

Gajdzik, B., & Grzybowska, K. (2012). Example models of building trust in supply chains of metalurgical enterprises. *Metalurgija-Zagreb*, *51*(4), 563.

Francis, P. M., Smilowitz, K. R., & Tzur, M. (2008). The period vehicle routing problem and its extensions. In *The vehicle routing problem: latest advances and new challenges* (pp. 73-102). Springer, Boston, MA.

Gendreau, M., Potvin, J. Y., Bräumlaysy, O., Hasle, G., & Løkketangen, A. (2008). Metaheuristics for the vehicle routing problem and its extensions: A categorized bibliography. In *The vehicle routing problem: latest advances and new challenges* (pp. 143-169). Springer, Boston, MA.

Golden, B. L., Raghavan, S., & Wasil, E. A. (Eds.). (2008). *The vehicle routing problem: latest advances and new challenges* (Vol. 43). Springer Science & Business Media.

Howard, R. A., & Matheson, J. E. (2005). Influence diagrams. *Decision Analysis*, *2*(3), 127-143.

Hunt, V. D. (1996). *Process mapping: how to reengineer your business processes*. John Wiley & Sons.

Jacobs, F. R., Chase, R. B., & Lummus, R. R. (2014). *Operations and supply chain management* (pp. 533-535). New York, NY: McGraw-Hill/Irwin.

Kagermann, H. (2015). Change through digitization—Value creation in the age of Industry 4.0. In *Management of permanent change* (pp. 23-45). Springer Gabler, Wiesbaden.

Laporte, G. (1992). The vehicle routing problem: An overview of exact and approximate algorithms. *European journal of operational research*, *59*(3), 345-358.

Lau, H. C., Sim, M., & Teo, K. M. (2003). Vehicle routing problem with time windows and a limited number of vehicles. *European journal of operational research*, *148*(3), 559-569.

Moeller, G. H., Mescher, M. A., More, T. A., & Shafer, E. L. (1980). The informal interview as a technique for recreation research. *Journal of Leisure Research*, *12*(2), 174-182.

Montemanni, R., Gambardella, L. M., Rizzoli, A. E., & Donati, A. V. (2005). Ant colony system for a dynamic vehicle routing problem. *Journal of Combinatorial Optimization*, *10*(4), 327-343.

OECD. (2015). *Excess capacity in the global steel industry and the implications of new investment projects.* Retrieved from http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=DSTI/SU/SC(2014)15/FINAL&docLanguage=En

OECD. (2016). *Research and Development, Innovation and Productivity Growth in the Steel Sector.* Retrieved from http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=DSTI/SU/SC(2015)5/FINAL&docLanguage=En

Osterwalder, A., & Pigneur, Y. (2010). *Business model generation: a handbook for visionaries, game changers, and challengers*. John Wiley & Sons.

Pires, N. R. (2012). *Determinantes do processo de Internacionalização das Empresas. Metalúrgicas Ibéricas* (Doctoral dissertation). Santiago de Compostela: University of Santiago de Compostela.

Popli, G. S., & Popli, R. (2015). Research Paper on Investment Opportunities in the Steel Sector of India on the Concept of Make in India.

Reuters (2018). *EU sets duties on Brazil, Iran, Russia, Ukraine steel*. Retrieved from https://www.reuters.com/article/us-eu-steel-tariffs/eu-sets-dumping-duties-on-steel-from-brazil-russia-idUSKBN1CB0L7

Reuters (2017). Retrieved from https://www.reuters.com/article/us-china-steel-mining/china-to-cancel-a-third-of-iron-ore-mining-rights-in-fight-against-smog-idUSKCN1C21I5

Reuters (2017). Retrieved from https://www.reuters.com/article/us-china-steel/getting-scrappy-china-iron-ore-demand-may-falter-as-steel-recycling-grows-idUSKBN19Q0U3

Roljic B., Tricoire F., Doerner K.F. (2018) Solving a Rich Intra-facility Steel Slab Routing Problem. In: Fink A., Fügenschuh A., Geiger M. (eds) Operations Research Proceedings 2016. Operations Research Proceedings (GOR (Gesellschaft für Operations Research e.V.)). Springer, Cham

Sandhya, V. K. (2013). Issues in Solving Vehicle Routing Problem with Time Window and its Variants using Meta heuristics-A Survey. *International Journal of Engineering and Technology*, *3*(6), 668-672.

Soltani, M. R., Sayadi, A. R., Monjezi, M., & Hayati, M. (2013). Productivity Improvement in a Steel Industry using Supply Chain Management Technique. *Int. Journal of Mining & Geo-Engineering*, *47*(1), 51-59.

Spierenburg, D., & Poidevin, R. (1993). *The History of the High Authority of the European Coal and Steel Community*. Weidenfeld & N..

Stefko, R., Slusarczyk, B., Kot, S., & Kolmasiak, C. (2012). Transformation on steel products distribution in Poland and Slovakia. *Metalurgija/Metallurgy*, *51*(1), 133-136.

Steel World. (2009). *Logistics: a key constituent for steel sector.* Retrieved from http://steelworld.com/focus1009.pdf

Toth, P., & Vigo, D. (Eds.). (2002). *The vehicle routing problem*. Society for Industrial and Applied Mathematics.

Tseng, Y., Yue, W. L., & Taylor, M. A. P. (2005). The role of transportation in logistics chain. Eastern Asia Society for Transportation Studies, Vol. 5.

Uckelmann, D. (2008, September). A definition approach to smart logistics. In *International Conference on Next Generation Wired/Wireless Networking* (pp. 273-284). Springer, Berlin, Heidelberg.

Voronov, A. (2012). *Analysis of door-to-door logistics in the steel industry.* Rotterdam: Erasmus University Rotterdam.

Walcarius, T., Houbraken, M., Audenaert, P., Pickavet, M., & Demeester, P. (2013). Modeling real-world vehicle routing problems with dependencies. In *6th Multidisciplinary International Conference on Scheduling: Theory and Applications (MISTA-2013)* (pp. 711-713).

Warren, K. (1987). *The American Steel Industry, 1850-1970: A Geographical Interpretation*. University of Pittsburgh Press.

World Steel Association. (2017). *World steel in figures 2017.* Retrieved from https://www.worldsteel.org/en/dam/jcr:0474d208-9108-4927-ace8-4ac5445c5df8/World+Steel+in+Figures+2017.pdf

World Steel Association. (2018). *Steel Statistical Yearbook 2017.* Retrieved from https://www.worldsteel.org/publications/bookshop/product-details.~Steel-Statistical-Yearbook-2017~PRODUCT~SSY2017~.html

World's Top Exports. (2018). Retrieved from http://www.worldstopexports.com/iron-ore-imports-by-country/