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Enhancing Cost Efficiency and Sustainability in the Supply Chain of Modular Construction: Designing a Data-Driven Solution

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Master's degree in Integrated Business Intelligence Systems

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TECNOLOGIAS
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Department of Information and Technology

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«You step onto the road, and if you don't keep your feet,

there's no knowing where you might be swept off to.»

- *J.R.R Tolkien*

Acknowledgements

Sometimes, when going through life with the winds, it becomes hard to stop and realize if you are heading in the direction you set sail towards, or if those same winds are guiding you to unexpected places, primed for discovery. These past few years, I’ve been “at sea”, and now comes the time to head towards land.

I want to express my gratitude towards those people without whom this would not have been possible.

First of all, to my supervisor, Professor João Carlos Ferreira, whose tireless availability, and insightful orientation, made it a much more “smoother sailing” than I would have expected.

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Finally, to all of the friends and colleagues, whose company I truly cherish, and that make up the crew of this ship.

To each and every one of you, my dearest thank you, and most honest hug. Thanks for guiding me ashore.

Resumo

A indústria da construção é, desde há muito tempo, um pilar do desenvolvimento económico, contribuindo significativamente para o PIB global, ao mesmo tempo que exerce um impacto ambiental considerável. O aumento da urgência em mitigar as emissões de gases de efeito de estufa e a crescente procura de práticas de construção sustentáveis levaram as empresas de construção a reavaliar as suas operações e a desenvolver estratégias inovadoras. Reconhecendo a necessidade de melhorar a logística de transporte para projectos de construção modular, o "dst group - Domingos Da Silva Teixeira, S.A.", uma empresa de construção proeminente, encontrou a necessidade de melhor antecipar os custos de transporte e reduzir as emissões de carbono. Na prossecução deste objetivo, o "dst group" recorreu à experiência da "Rangel Logistics Solutions", uma empresa de logística estabelecida, para enfrentar este desafio multifacetado. Esta dissertação explora o trabalho realizado na “Rangel Logistics Solutions”, dando ênfase ao processo de concetualização e desenvolvimento de uma solução de TI inovadora, orientada por modelos preditivos de custos e emissões.

Palavras-chave: Construção modular; Transitários; Inovação na cadeia de abastecimento; Design de aplicações; Aprendizagem automática

Abstract

The construction industry has long been a pillar of economic development, contributing significantly to global GDP while simultaneously exerting considerable environmental impact. The increased urgency to mitigate greenhouse gas emissions and the growing demand for sustainable construction practices have prompted construction companies to reassess their operations and develop innovative strategies. Recognizing the need to improve the transportation logistics for modular construction projects, "dst group - Domingos Da Silva Teixeira, S.A.”, a prominent construction company, found the necessity to better anticipate transportation costs and reduce carbon emissions. In pursuit of this objective, “dst group” enlisted the expertise of "Rangel Logistics Solutions," an established logistics company, to address this multifaceted challenge. This dissertation explores the work undertaken at Rangel Logistics Solutions, emphasizing the process of conceptualization and development of an innovative IT solution driven by predictive models for cost and emissions.

Keywords: Modular Construction; Freight Forwarding; Supply Chain Innovation; Application Design; Machine Learning

Contents

Glossary

Abbreviations

BPMN - Business Process Modeling Notation

DST – dst group

EU – European Union

FF – Freight Forwarder

FTL - Full Truck Load

GHG – Greenhouse gas

INEGI – Institute of Science and Innovation in Mechanical and Industrial Engineering

IT – Information Technology

LTL - Less-than-truckload

ML – Machine Learning

RCP – Rangel Customer Portal

RRF – Recovery and Resilience Facility

RRP – Recovery and Resilience Plane

TMS – Transportation Management System

List of Figures

List of Tables

CHAPTER 1

Introduction

Modular construction has gained prominence for its potential to reduce construction timelines, minimize waste, and enhance project quality through the off-site fabrication of building components. However, the transportation logistics associated with modular construction have posed substantial challenges. These include unpredictable costs, inefficient route planning, and the notable carbon footprint generated by transportation activities. These challenges underscore the need for a comprehensive solution to optimize transportation logistics in modular construction projects.

1.1. Motivation

Modular construction is defined as "a process in which a building [or component] is constructed off-site, under controlled plant conditions, using the same materials and designing to the same codes and standards as conventionally built facilities" [1]. Although these constituent products or components are made autonomously, they have sufficient compatibility to be combined, using equivalent design specifications, to develop an integrated system [2]. The modular construction market has been experiencing steady growth, driven by its benefits. More companies are entering the modular construction space, leading to increased competition and innovation. The construction industry contributes to about 13% in the world's gross domestic product (GDP), which is rising rapidly and may become 14.7% till 2030 [3], and since more and more use cases are being tried that employ modularity and prefabrication, it is expected that the sector is going to grow as well, to up 130 billion USD by 2030, with potential savings of 22 billion USD in comparison with traditional construction methods [4].

1.2. A consortium towards EU objectives

In order to help European Union (EU) member states recover from the impacts of the COVID-19 pandemic, the EU is providing financial support through its Recovery and Resilience Facility (RRF). The RRF is part of the larger EU recovery package called NextGenerationEU, which was established to stimulate economic growth, foster resilience, and drive the green and digital transitions across Europe. [5].

By giving them sizable financial resources to invest in important fields including public health, sustainable development, digitalization, and job creation, the RRF seeks to address the issues faced by member states. It aims to accelerate the global economic recovery and give EU nations a more secure and resilient future.

Portugal's Recovery and Resilience Plan (RRP) is the national plan created to access and make use of the money provided through the RRF. The RRP for Portugal is intended to address both the country's short-term recovery requirements and its long-term structural problems. Resilience, climate transition, and digital transition are the three key pillars that the strategy is built upon. [6].

The RRP's resilience pillar intends to improve the social safety net, strengthen Portugal's healthcare system, and increase the resilience of the government and legal system. The climate transition pillar prioritizes spending on decarbonizing the economy, energy efficiency, sustainable transportation, and renewable energy. Finally, the goal of the digital transformation pillar is to ensure digital inclusion and cybersecurity while promoting digitalization in several industries, such as public services, healthcare, and education. For the topic of this text, these final two are very crucial.

Portugal's RRP is based on a thorough examination of the requirements and priorities of the nation, which took into account comments from a number of different stakeholders, including the government, civil society, and private sector. The Portuguese government's executive branch wants to use the RRF investment to carry out specified projects, reforms, and policy changes, which are detailed in its plan [7].

"R2U Technologies | modular systems" (R2U) - as part of the RRP - represents a collaborative effort between various entities within Portugal, mostly represented in its northern region. This consortium aims to address crucial challenges in the field of construction, by leveraging the resources and expertise of its participating partners. With a focus on promoting innovation, sustainability, and development of modular construction products and processes, R2U Technologies aims to drive positive change and generate valuable insights in this area. By bringing together a diverse range of stakeholders, it seeks to create a robust framework for research, development, and implementation of solutions that can contribute to the overall growth and prosperity of this new paradigm in the construction sector.

For "dst group" (DST), a Portuguese company created in the 1940s with activities in construction and logistics, innovation plays a very relevant part in not only the execution, but also as a pivot for the digitalization and sustainability optimization of the construction supply chain [8]. In a shift of focus towards modularity and prefabrication in opposition of traditional construction methods, and looking to address the challenges brought by the added complexity of this techniques' methods of transportation, the aid of a logistics expert was needed.

In response to its needs, DST engaged Rangel Logistics Solutions (Rangel), an industry-renowned logistics company with a wealth of experience in devising innovative transportation strategies. This expertise derives from being a well-established player not only in the Portuguese, but international markets as well, serving as a one-stop-shop for all logistics related needs, making them an ideal partner for addressing the complexities of modular construction project logistics. Rangel's services include, among others: land, air and sea freight, customs clearance, and critical transport, providing a wide-ranging know-how and expertise. As a freight forwarder (FF), the company is well versed in the planning and execution of transportation requests but does not in itself own most of all the equipment – trucks, containers, ships, planes – that it fills with customer cargo, and instead acts as an intermediary in this part of the supply chain.

Rangel's role in the partnership encompassed: strategic analysis, by conducting a comprehensive analysis of existing transportation processes, routes, and associated costs to identify opportunities for optimization; envisioning how the sustainability objectives of its client would be better kept through equipment and route optimization; and conceptualizing and developing an IT (information technology) solution driven by predictive models to enhance the accuracy and efficiency of transportation planning.

Towards this last goal, and since academic expertise was seen as an unwavering source of state-of-the-art academic knowledge, the "Institute of Science and Innovation in Mechanical and Industrial Engineering" (INEGI) was invited to collaborate in this work package and help in creating and implementing predictive models.

1.3. Research Objectives

This master's thesis aims to provide an in-depth understanding of how the manufacturer's need to enhance the predictability of transportation costs and carbon emissions in modular construction projects was approached. It delves into the effort to design and start of development an innovative IT solution that leverages predictive models to optimize transportation logistics.

It details the methodologies, strategies, and techniques employed by the author, as part of Rangel Logistics Solutions' team, in designing the application and its requirements, its systems architecture, as well as providing a basis for the development work across multidisciplined teams and partners.

This work mainly focused on:

1. Analyzing the flaws and improvement opportunities in the current business processes;
2. Conceptualizing a critical solution for the client's needs;
3. Mapping new business processes as well as new IT system architecture;
4. Facilitating development of said solution at Rangel, by clearly defining requirements, performing validation with stakeholders, and helping in decision-making, as well as other needed tasks in data engineering;

1.4. Outline of the dissertation

Having its objectives outlined, this dissertation is composed of five chapters, including the introduction of *chapter 1*. The concurrent ones are as follows:

Chapter 2 presents a state-of-the-art analysis in the implementation of modularity and prefabrication in the global construction sector, the expectations for further maturation of these techniques, and finally an outline of the digitalization of the sector and its supply chain.

Chapter 3 delves into the definition of objectives for a solution that works towards solving the problem identified in chapter 1, with the rationale behind the decisions being clearly stated. This chapter also focuses on the current systems and business processes in place, from the FF's point of view, and highlights specific opportunities for improvement, and finally, the comparison between two different software architectures for the solution, followed by how and why one was chosen over the other.

Chapter 4 details the hands-on design and specification work done, to allow for the development of the application. In this chapter are found the work of identifying and validating of impactful variables, understanding how to consider GHG emissions in historical transportation data, the strategy for development and requirements of a web interface between customer and FF, and how the different stakeholders validated the work done, during and after developments.

Chapter 5 serves as the summary of the work done, with a focus on how it addresses the stated objectives, while exposing its limitations and contributing by highlighting important future work for the field and this specific problem.

1.5. Privacy issues

In this dissertation, it was imperative to navigate the intricate intersection between academic research and the safeguarding of trade secrets and proprietary business data held by the interested parties. With that in mind, along the text, certain liberties were exercised, leading to modifications in the flowcharts of business processes, datasets, and descriptions of protected IPs. In the case of recent business data, these modifications were applied with care to maintain the essence and underlying trends of the data, while eliminating any identifiable markers that could compromise the anonymity and proprietary nature of the information. When discussing how a business process takes place, particularly when articulating between different teams inside the same organization, the method was to focus on describing what the business landscape in the sector already knows to be a general case, and that common sense would deem impossible to omit.

CHAPTER 2

State of the art

The construction industry, traditionally characterized by fragmentation and inefficiencies, has witnessed a transformative shift with the adoption of supply chain technology in the context of modular construction. The integration of technology into supply chain management processes has become instrumental in optimizing the production, logistics, and assembly of modular building components.

This literature review focuses on the evolving landscape of modular construction and its profound interplay with supply chain technology. By surveying existing research and industry developments, this review seeks to provide a comprehensive understanding of how supply chain technology is reshaping the modular construction sector.

2.1. Benefits of modular construction and prefabrication

2.1.1. Why build modularly?

This technique is, more often than not, in the literature, said to bring many advantages forward, and can be split into 5 main axes: Timing, Cost, Disruption/Safety, Quality, and the Environment. These benefits arise from different realities, as can be seen in Figure 2.1, and are detailed in the following subsections.

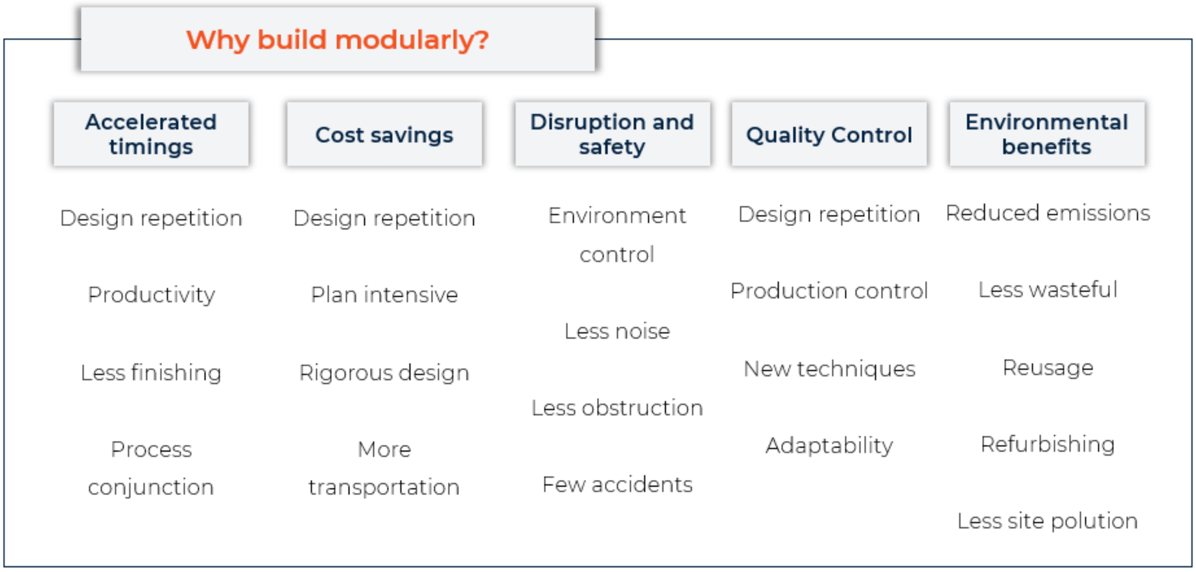

Figure 2.1. – Advantages of modular construction

2.1.2. Accelerated construction time

The use of prefabrication is consistently found to reduce project timelines significantly. This is due to repetition in designs, enhanced productivity in factory environments, less finishing work, and simultaneous off-site fabrication and on-site preparation. In a 2019 report, McKinsey & Company suggested that “using 3D volumetric modules can deliver 20 to 50 percent schedule compression” [4].

Multiple analyses suggest that due to the fragmentated nature of production, if correctly implemented, the improvements in schedules versus traditional methods of construction are relevant [9]–[11].

2.1.3. Cost savings

Although values associated with initial cost, capital cost, and capital payback period may impede the widespread adoption of off-site construction [12], studies imply that modular construction can be cost-effective, especially for repetitive building designs. Although some authors suggest that in the material production stage, modular construction might be slightly more expensive than the alternative, that is, regular methods of reinforced concrete [13].

However, considering the potential for reusing the individual modules, the reduction in the material cost made possible by the mass production of said modules, and improved work productivity due to learning effects, this premium is partially offset by the considerable economies that can be achieved, thus lowering the unit cost of production over the module’s entire life cycle [13].

In its 2019 report, McKinsey & Company also identified “an opportunity for 20 percent savings—but at a risk of up to 10 percent cost increases if labor savings are outweighed by logistics or materials cost”. This was particularly caused by savings in material costs and on-site labor, but with a cost increase in logistics, while adding to the balance the off-site manufacturing and factory cost [4]. This reality also appears when evaluating the costs per square foot in multiple case studies of permanent modular constructions across several typologies [14]. The authors indicate that, when building modularly came at a premium compared to conventional construction, the root cause was those of “additional materials required for structure and transport, transportation costs for large load permits and lead cars, time lost due to permitting, and time lost due to transportation of long distances”.

2.1.4. Reduced on-site disruption and safety concerns

Another significant advantage of modular construction is the minimized disruption to surrounding communities. Since the modular units are produced in the factory, there is less disturbance from workers and equipment. In addition, most of the materials are transported to the factory and not directly to the build site, minimizing the amount of transport trips needed [15]. Not only that, but by removing labor-intensive construction activities from the build site and instead placing the prefabrication activities in a controlled factory environment, a much safer environment is fostered in the construction site [16].

2.1.5. Quality control, adaptability, and innovative designs

Designing for the manufacture and assembly in the construction sector has proved to be a relevant way of improving building quality, with no compromises either in materials or installation [17]. At the same time, the flexibility and adaptability of this construction process is praised [8], [18] as, through combining a variety of modules in a concrete or steel frame, a wider array of design opportunities arises, especially for mixed-use commercial and residential buildings [18].

2.1.6. Environmental benefits

In addition to accounting for 34% of global energy demand [19], the construction industry also accounts for more than 30% of global carbon emissions, an alarming proportion, indicating that a reduction in carbon emissions from the construction industry is inevitable [13]. If compulsory mitigation measures are not taken, this percentage is believed by some academics to double in the next 20 years, due to inefficiencies of existing building methods and increased urbanization [3].

It has been shown that greenhouse gas emissions for modular forms of construction were, on average, less than their conventional techniques [20]. Production of the modular units and building construction in a controlled environment such as a factory reduces waste through escaping upstream rather than diverting downstream through disposing of it. Modular construction can thus, by its very nature, minimize the impact on the environment and inherently promote sustainability [21]. There is also the chance to reduce the demand for raw materials and energy to create a new building. In addition to being less wasteful, as mentioned, due to being produced in a factory, there can be controlling of inventory, and units can even be reused, refurbished or moved from site to site [21]. There is the added privilege of using mono-materials, while reducing the number of constituent components [8]. Finally, the modular structure is completed in a factory using dry resources. Therefore, the potential of high levels of moisture trapped in the new construction is eliminated, so that the quality of air is improved.

Considering all of the potential benefits of prefabrication, an operational carbon reduction of around 3% and actual carbon reduction up to 15% is to be expected, reducing the environmental impacts of the construction industry [22]. Nevertheless, the sector has reached pre-COVID pandemic levels of CO2 emissions and energy use and is currently "not on track to achieve decarbonization by 2050" according to the United Nations Environment Programme [19].

2.2. The role of supply chain

In the realm of the supply chain, a great potential for improvement is identified [4], [23]. Due to the special characteristics of the prefabrication of house modules, a thorough and well organized supply chain is essential, in order to minimize the impact of its stated risks [24], [25].

Multiple barriers have been identified as contributing to the lack of adoption of supply chain management, most of them relating to lack of information and technologically innovative mindset in corporations [26]. In order to reduce the challenges of this construction technique, robust logistics planning diligences should be done [25].

A collaborative approach is essential for correctly addressing the uncertainties that arise from the fragmentation of the supply chain in the sector [27]. It is imperative to synchronize the various stages of design, manufacturing, transportation, storage, and installation [28], and yet, the engineering and construction sector is still some of the world's least digitized [29], which is shown to be an incredible hinderance towards that goal.

2.3. Remaining Challenges

In summary, while modular construction offers numerous advantages, challenges persist, including regulatory hurdles, transportation logistics, and the need for skilled labor in both manufacturing and assembly. Researchers often emphasize the importance of addressing these challenges to maximize the benefits. However, some strides are being taken, mainly in the processes of construction itself [30], with focus on the principles of lean manufacturing [31], [32], and manufacturing and assembly-enhancing solutions [24], [31], [33]. A veritable amount of research is being conducted in looking at emerging technologies and how they can be applied to the development of the sector [34].

Particularly in the scope of transport and logistics, a few critical risk factors have been identified as vital in the adoption of volumetric modular construction, namely delays in finishes due to planning - early or late delivery of modules, poor marking and improper buffer space onsite – others due to the handling of the merchandise, and lastly the complexion of restrictions, both in size and weight for transportation, but also restrictions of rules and regulations of the routes and transport vehicles themselves [24], [35].

While some are being addressed, as technologies that allow for real-time visibility of manufactured components are already being used in specific projects [16], others play a big part in the success [or lack thereof] of any given project and are in need of innovative solutions.

CHAPTER 3

Conceptualizing the Solution

When elucidating about the conceptualization or design of an ideal solution for DST's problem case, we start by getting a good picture of how the logistics operations influence a construction company with a large proportion of prefabrication activities. Secondly, we explore the current process in which a customer receives a price from Rangel, and how it needs to change in order to pursue this project's requirements. Finally, we present the case for the use of predictive models within the end product and conclude with a complete explanation of the definitive IT solution design proposed and its implication in Rangel's future IT architecture.

3.1. Added complexity in construction companies' logistics

Having started work on the specification of the required output for the logistics component of the R2U Technologies agenda, various meetings were conducted between the staff of the logistics expert (Rangel) and the manufacturer (DST). The main result of said meeting was establishing how accounting for logistics or transportation activities varies from the traditional methods and modular construction, first-hand.

First, keeping in mind that inserting an industrialized production step is the main disruptive aspect of this activity, one must make the very clear distinction between having, or not, this intermediate phase of production, as can be seen in Figure 3.1. Prefabricating eases the assembly/construction work required at the build site but adds the much more complex need for higher degrees of production logistics and the more complex movement of finished goods, i.e., the modular components. The movement of goods would function in a very dissimilar way. Instead of standard transport operations, we are looking at a large volume of outbound movements of modules (Figure 3.1), that have the potential to become very specialized and costly, if not planned with utmost care.

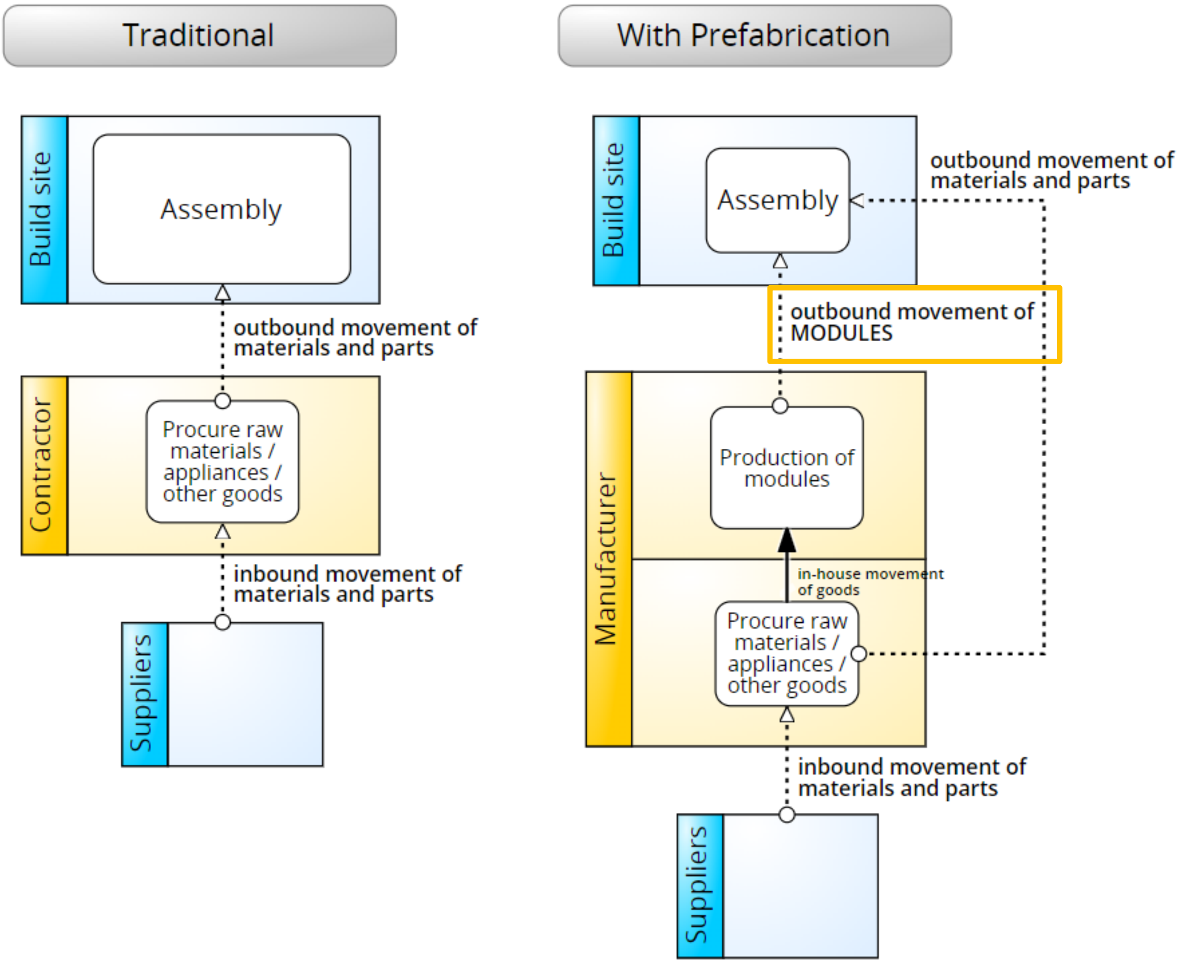

Figure 3.1. - Traditional vs Modular Supply Chain

3.1.1. Different approaches for planning and execution

This necessity to carefully plan and design, followed by an assertive execution of the projects, becomes more apparent if the process is divided into two phases, namely, a Planning Phase, and an Execution Phase. From talks with DST, these two phases comprise different economic cases and generate distinct addressable needs. Conclusions can be summarized as follows:

3.1.1.1. Planning/Design (Inbound & Outbound)

First and foremost, it is important to say that there are a multitude of sides to the equation of evaluating if a construction project should be pursued or not. Aside from the aesthetic elements, choosing materials without considering their cost (including transportation) would be a disaster for any execution. This side of the supply chain belongs to the designation of "inbound logistics" [36]. Due to recent instabilities with how well supply chains will fare around the globe [37], and also on the instability that brings to the bottom line of all the players in the value chain, it was indicated by the manufacturer that predicting accurately how much freight was going to translate into production costs and GHG emissions was of the utmost importance.

When thinking about prefabrication before a project has started, i.e., when designing a module or components, architects and engineers must also keep in mind the cost of transporting finished (or semi-finished) module(s) to their intended construction sites. In addition, another problem arises when evaluating viability means looking at a specific address to "place" the finished product, i.e., whether it can even be delivered to that location in a cost-effective manner. A project can be perfectly economically viable if the intended site is on a well-connected suburban area, but fall apart if the carrier wants it transported to the center of a city, where circulation restrictions, terrain, and pre-existing construction influence costs positively. These factors can be included in the category of "outbound logistics" [38].

Any solution that hopes to address these issues should provide the most intuitive and assertive way possible in which to plan for all contingencies.

3.1.1.2. Execution/Production (Inbound & Outbound)

After the planning phase, in a modular construction project, comes the execution proper. In inbound logistics, more intuitively, but still relevant, is the need for quick and accurate pricing for the transportation of raw materials, built components, and other necessary technologies, from a myriad of suppliers to the factory environment once a project is running its course. This is a standard operation for a FF, and the improvement avenue would be to maximize the number of supplier alternatives considered, supported by an agile quotation process, maximizing the amount of information that can be delivered and winning more transportation bids. In outbound logistics, speed and accuracy are also must-haves when transporting the finished modules to their destinations (build sites), but with the added complexity of considering if the characteristic of any module allows it to be transported in a given route, date, and to its final location.

Much less standard for the operation of an FF is the regular estimation of GHG emissions for a given route. Towards this stated project goal lies a great leap forward in the innovation of a process that provides the expected emission values to any potential client, following its internal carbon emission measuring protocols. The sustainability of the supply chain is of great importance and must be reliant on correctly predicting what impact a given project would have on the environment, through the consideration of, and attempt at minimizing, its carbon footprint.

Not only does the manufacturer want to get the best price for their needs and minimal carbon emissions, selecting the best supplier on a specific date, but also does the FF wish to have the privilege of giving an accurate and fair price as quickly as possible, with a well calculated margin according to market conditions. The FF's result is thus only impacted by the number of shipments it provides for the client (manufacturer) to which it provided quotes. Even though the information is relevant also in the planning phase, it is not expected that this data should be under a "paywall" and would instead be freely provided to the client – up to a reasonable extent – with the expectation of being contracted to provide the service of transportation.

3.2. Current quotation process

The first step in most business process understanding endeavors is to interview the personnel responsible for executing it. In this study, a description of the quotation business process - currently in place - of giving a price quote to a customer is provided. These descriptions are based on extensive interviews with sales [commercial] staff; the business analytics team, owners of the business data; the operational team, who conduct the planning and good execution of trips; and the company's upper management. The questions and summary of said interviews can be found in Appendix A.

Through these interviews, an insight into the information that needs to be provided by a potential client, plus the ones that have an impact on the cost and the asking price, was achieved. Stemming from this knowledge collection, a description of the current quotation process is provided in the following section, as well as the available variables in the current data schema.

3.2.1. Current quotation process

The process through which an asking price is given to the client always starts with a request by a potential client, for a quotation, based on characteristics that they specify in their e-mail or phone call. This business process is illustrated in Figure 3.2. In some cases, where the information provided is not enough to calculate the cost of that operation for Rangel, the sales representative, who needs to enter the information manually in the Transportation Management System (TMS), may need to ask the client for more info. In the case of FTLs (Full Truck Load), LTLs (Less-than-truckload), or generally oversized loads, the price should be calculated by the operational team as, in this case, that price is more accurately given by the operational team members. This is because operational staff plan and manage the totality of trucks and containers' available space and are thus not as constrained by cost calculation standards by number of packages, for example.

Most times, though, the client will ask for a price for a Groupage operation and not an LTL or FTL, and his final asking price is calculated based on an interaction with the TMS - where standard estimated transport cost tables are loaded into, based on agreed upon tariffs with partner shipping companies. From the info provided by the client, the TMS will compute a cost value for reference, to which the sales representative will add a profit margin, and propose that value to the customer as the price for that shipment.

It is also important to note that this process is made separately for the road portion of the trip and for its aerial or maritime component, and provided that a shipment has the need for those two phases, both must be taken into account together.

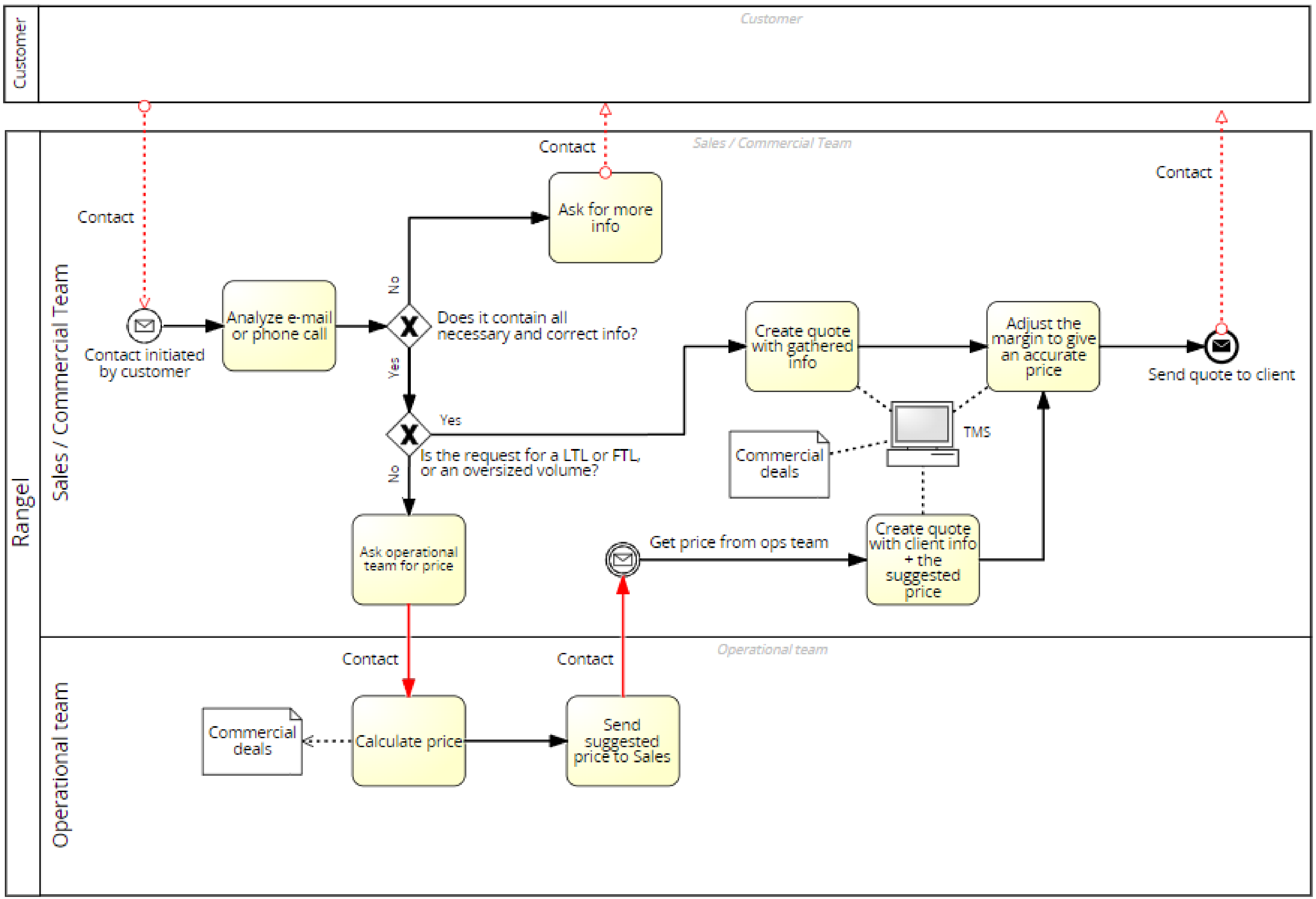

Figure 3.2. - Current quotation process

3.2.2. Method for obtaining variable value and considerations

Another valuable insight gained shadowing the business users was how these variable values were obtained, and the understanding that a great number of considerations and criteria were being applied subjectively by the commercial and operational teams to correctly evaluate if a given transportation is even possible, and if so, in what equipment, by what route, and in what modality.

In practice, most of the variables with impact on the price are currently provided by the client, then fed into the TMS by the sales representative or the commercial staff. Table 3.1 contains each variable, how it reflects on the price of the shipment, and how it is inserted by the sales representative into the TMS.

Table 3.1. Customer input variables

	Field	Impact on price	Inserted as
Customer Input	Location of Origin	Distance	Postal code
	Location of Destination	Distance	Postal code
	Weight	Chargeable weight	Kg
	Length	Chargeable weight	m
	Width	Chargeable weight	m
	Height	Chargeable weight	m
	Intended load date	Seazonality (dates)	Date
	Intended unload date	Seazonality (dates)	Date
	Intended load hour	Seazonality (dates)	Hour
	Intended unload hour	Seazonality (dates)	Hour
	Package Quantity	Tariff	Integer
	Package Type	Tariff	Multiple options
	Service Level	Service Level	GRP/LTL/FTL
	Service tipe	Immediacy	Normal / Urgent
	ADR	ADR* costs	Multiple options
	Non-overlapping/able	Occupies more volume	Multiple options
	Additional Services	Insured or not	Y/N

Nonetheless, there are other considerations that are taken into account, such as every law and guideline of equipment capacity, route restrictions, etc., that are currently left to the subjective experience of sales and operational teams to consider how they affect the cost of the trip, but also how they manifest in the margin that can be negotiated with the client, as is explicit in Table 3.2. Specifically, laws and guidelines affect what trips can be performed (e.g.: if a truck will be able to circulate in a specific urban area) and in what equipment – that is, what is the best option of container or truck to carry a set amount of packages with set height and width – but they can also affect price, as some oversized loads are required to be escorted by pilots or have specific authorizations, any of which entails added operational costs. The modality and route taken by a given transport is subjectively optimized by Rangel's team as well. For example, if transporting by truck from Portugal to a port city in Spain should be less efficient than by sea, the team must be able to decipher that, and point to the best option. Finally, the commercial teams determine if they want to add a fuel surcharge or not (that is based in market fuel prices), and what Incoterm is to be chosen, i.e., what actions of the whole operation will the client pay for (from loading, unloading, customs clearance, documentation, etc.).

Table 3.2. - Staff inputs

	Field	**Influences:**
Laws and guidelines	Weight limits	Route restrictions / Equipment
	Length limits	Route restrictions / Equipment
	Width limits	Route restrictions / Equipment
	Height limits	Route restrictions / Equipment
	Time of day restrictions	Route restrictions / Equipment
	Needed add-ons and escorts	Circulation restrictions / Equipment
Determined by FF staff	Route	Route restrictions / Equipment
	Fuel surcharge	Negotiating capacity
	Road / Air / Sea	Modality
	Equipment type	Equipment choice
	INCOTERM	Who pays for what

3.2.3. Opportunities for improving

After conclusion of the aforementioned process schematization and analysis, a critical analysis of the business process outlined in section 3.2 was conducted, leading to the identification of opportunities for improvement, and that will serve as key points of order for the proposal of the most well-suited end-product, as a solution to address DST's problem statement.

Firstly, the process is not sufficiently agile, since the number of direct contacts made between different stakeholders was considered to be much higher than needed. As an example, the customer should not send an e-mail to a sales representative and keep providing more info through e-mail if they could by themselves fill it out; the sales team should not need to consult the operational team to assess the occupation status and remaining capacity of truck outbound to a certain destination if that information was more readily available to them.

Secondly, it is deemed truly subjective. Not only the standard tariffs, that the sales team currently uses to estimate costs could be more often updated, or entirely sidelined, evolving into a price estimation based on historical data, but there are a variety of identifiable considerations and heuristics that they apply that could be brought into view.

In addition, there is a lack of systematized and quickly accessible information, as all of the laws and guidelines that the staff have memorized and that are subject to constant update by a myriad of national and international regulators, could be automatically taken into consideration, to centralize truth and avoid human error.

Finally, the GHGs emitted by each trip, be it by truck, ship, or plane, are not currently displayed or given to the customer. In any case, the methodology for assessment of GHG emissions should be perfected, and incorporated in the TMS databases, in order to then be able to assign to each shipment the extent of its carbon footprint, and present that as valuable information to customers.

3.3. Decision to incorporate predictive models

In the early debate sessions, a clear necessity was brought up by the manufacturer (DST): to work on a way to leverage predictive models, so that project managers could systematically analyze a wider array of factors and variables and achieve more accurate planning and results. The advantages to these algorithms' usage was summarized as follows.

For cost optimization and control, the integration of predictive models would provide DST's project managers with a clear understanding of transportation expenses, allowing for improved budgeting and cash flow management, ensuring financial stability throughout the whole process.

Effective resource allocation is a fundamental aspect of any industrial planning and production. Predictive models would enable project managers to allocate resources, such as manpower and equipment, more efficiently, while also allowing for more accurate sequencing of transportation and assembly activities. Moreover, by identifying routes or transportation methods associated with higher costs, alternative strategies can be explored to mitigate expenses and optimize resource utilization. When it comes to delivering a module to the build site, by considering the estimated transport variables, one can determine the optimal sequence and timing of module deliveries, minimizing idle time and maximizing overall productivity. This approach ensures that modules arrive at the construction site at the appropriate time, facilitating a streamlined workflow and minimizing project delays;

When it comes to managing risk, transport costs in any kind of industry can be influenced by external factors such as fuel price fluctuations, changes in road conditions, or alterations in weather conditions. Predictive models would assist in assessing and managing these risks proactively. Manufacturers can identify potential risks and their impact on transport costs, enabling the development of contingency plans to mitigate disruptions and uncertainties, ultimately ensuring smoother project execution.

Finally, since construction activities often involve engaging multiple vendors for module fabrication, transportation, and assembly, predictive models of transport costs and GHG emissions can facilitate informed decision-making when selecting vendors, be it of raw materials, finished products, or the freight itself.

3.4. Definition of the solution

As a result of the aforementioned process of discussion, debate, and ideation of what a solution to the customer's need would look like, a draft of a desired application was developed, constituted of five modules, as seen in Figure 3.3.

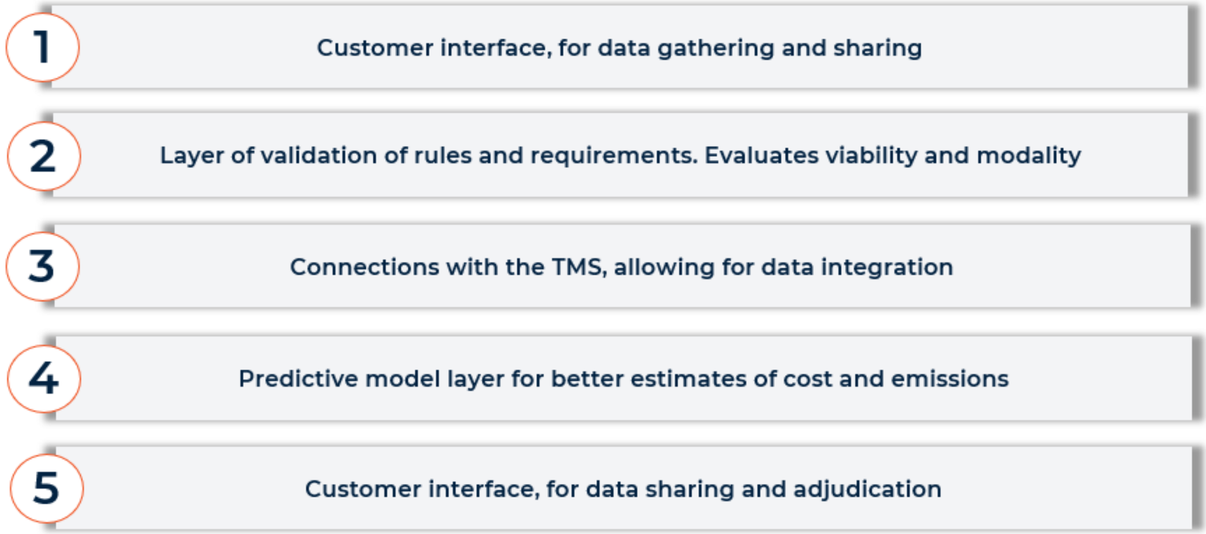

Figure 3.3. – 5 work modules of the solution

Module 1 - An interface made available to the customer, for gathering of data necessary for the quotation process, and for back-and-forth communication;

Module 2 - a layer of validation of certain rules and requirements, that evaluates the viability and modality for a shipment, and that attributes the optimal route and equipment for it;

Module 3 - a connection with the Transportation Management System (TMS) in use, allowing for the integration of quotation data and generation of price and emission proposals;

Module 4 - an intermediate layer capable of running predictive models with the inputs gathered, with target variables of cost, asking price, and emissions;

Module 5 - an additional interaction interface for a customer to analyze the results of the models' predictions and "commanding" the creating of a quote and shipment in the TMS, that is, adjudicating a given transport operation. In order to most accurately describe the interaction between the solutions' modules, within the context of simulating the price and emissions for a given transport, a BPMN-based flow of how the business process of quotation at Rangel, in this future scenario, is provided in Figure 3.3 and in the following description.

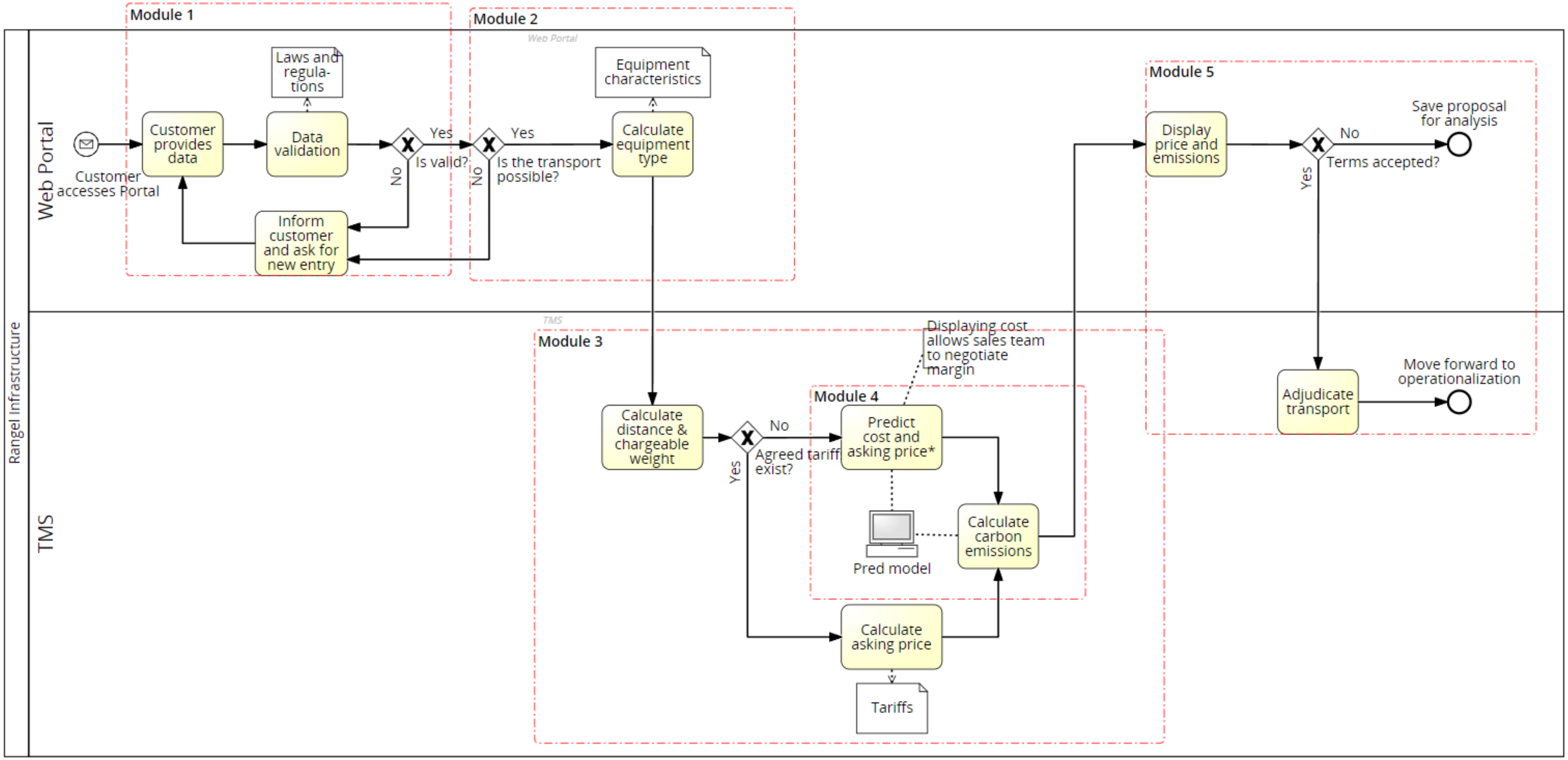

Figure 3.4. – Intended quotation process

The process of giving a price and emissions estimation, as an output, to the client, would begin when they access that part of the Rangel Customer Portal (RCP), a web application (module 1). The customer would then be asked to submit the required data for the validation and computation of the outputs. Assuming the data entered passes validations of form and context, a comparison would need to be made between what is asked and what is possible, that is, if transportation between specified addresses and/or dates is even possible. Based on the characteristics of the intended goods, i.e., the values of the variables of dimension, the addresses of loading and unloading, and intended dates and hours for loading and unloading, highlighted in Table 3.1, the possible modes of transportation are selected (module 2).

Next would come suggesting an asking price, based on the distance and chargeable weight (that itself is a conjugation of the variables of weight, height, width, and length (see Concepts section) of the load. This part of the process would start by entering values of the variables, automatically, into the TMS. If there is already an agreed upon price with the customer, the asking price should be retrieved based on tariff tables. If not, a predictive model would come into play. This model must be trained with the largest amount of quality-assured past shipment data from the FF, in order to accurately provide a cost and price estimation. It is important to predict cost and not only the asking price, since the sales representatives often negotiate the margin in their commercial activity and would benefit from the insight into the operational cost of the service.

When it comes to the prediction of GHG emissions, it should also be done based on the amounts emitted by past FF shipments but must still be calculated even if the price is already negotiated, as it is considered a valuable insight by all parties.

Price and emissions would then be provided to the client via the RCP, allowing for their review, and culminating in either an acceptance and subsequent adjudication, starting the operationalization leg of the process in the TMS, or a non-acceptance, saving the outputs as a mere simulation for analytical purposes.

3.5. Illustrative cases of new process

Although the explanation of the quotation process in section 3.4 is the simplest way to understand the constituent modules of the solution and their interactions in the final solution, two illustrative cases are hereby presented, one for each production phase for outbound logistics of prefabricated modules.

Suppose that the modular construction company wishes to produce a module of height of 3.2 meters, width of 2 meters, and length of 6, and send it over to Bordeaux, without dangerous goods. It is to be loaded on the 5th of September and unloaded on the 7th.

3.5.1. Planning phase

When in the design (or planning) phase, the valuable insights are if the transport is possible based on those criteria, and to get a rough estimation of price and emissions.

The manufacturer would then insert the module’s information into the Customer Portal and will get confirmation that the data inserted has been validated, and within a small timeframe, get a reply with the possibility of realizing the trip. If for some reason the trip is not possible, they would get not a confirmation, but a warning explaining what criteria makes it so.

In the background, a request will be sent to Rangel’s systems for a price and emissions simulation, with the interactions between them being further developed in Sections 3.4. and 4.4. Predictive models trained on Rangel’s historical data will estimate those values based on the cargo characteristics inserted.

The client will then be provided with this information, and keep it for themselves, since their project is only in the planning phase, and this consultation will not be followed up with a shipment service adjudication.

3.5.2. Execution phase

Be that as it may, in the execution phase, the client’s focus is not so much on if the trip is even possible, but on getting the most advantageous quote. Thus, the aforementioned characteristics are inserted in the systems, and although previously the price and emission estimation served merely as a guiding value for cost control, resource allocation, etc., now it is that estimated price that is going to be paid by the client to Rangel.

The only difference in system interactions, in this case, is that the client can, and does, adjudicate a shipment, communicating to Rangel’s systems that a shipment operationalization must be started.

3.6. Changes in Rangel’s IT architecture

As stated, an intelligently designed IT architecture will serve the good conduction, implementation, and longevity of impact of the solution. First and foremost, it provides a clear roadmap for the alignment of technological resources with the project's objectives, thus minimizing the risk of resource misallocation and making sure that the contracted milestones are achieved. Moreover, a well-defined IT architecture facilitates seamless communication and integration among disparate systems and applications, namely the customer interfaces (RCP), the TMS, the predictive model layer, and downstream analytical tool. The goal is to facilitate data sharing, process automation, and near-real-time decision-making. This, in turn, will enhance the project's agility and the organization’s responsiveness in adapting to evolving market demands and operational challenges.

3.6.1. Communication protocol

In order to arrive at the most effective IT system architecture, across multiple discussions with the manufacturer, a tailored communication protocol was aligned, with the specific requirements of the project. This process involved a systematic evaluation of the anticipated workloads associated with planning and execution phases, considering both inbound and outbound logistics, with the aim of establishing a communication framework that effectively addresses the demands of the project's operational dynamics.

The estimation was conducted having in mind Execution and Planning simulations for both the inbound and outbound phases (see section 3.1.2). A set of key guiding questions was provided to the manufacturer concerning all these phases, consisting of the following queries:

« In general:

- How many quotations will be done, by material and in the execution phase, for a typical construction?
- How many different vendors supply a typical construction?
- How many vendors supply each material in a typical construction? »

« On a weekly basis:

- How many quotations will there be for inbound logistics, for the planning and execution phases?
- How many outbound logistics (3D and 2D construction) quotations will be consulted, for the planning and execution phases? »

These questions were decided upon considering the relevance of the weekly workload on Rangel's IT infrastructure, as well as the capacity to analyze the number of simulations, adjudicated transports, and acceptance rate. Although the concrete answered amounts may not be specified in this text for confidentiality concerns, an outline is provided below.

For inbound logistics operations, it is simple to assume that a lot of requests are done when designing a module, while trying to evaluate the feasibility of using a given material or component in production. Projects still in the design phase will require, at most, 10000 quote requests. Still, in the execution phase, although the use of certain materials might already have been decided on, the search needs to be more refined, and that will not result in fewer simulations. We will then assume a maximum of 10000 quote requests per modular construction project.

Conversely, in outbound logistics, the number of simulations (quotes) will be much less. The production of tens of modules is expected, but many are equal. All of these won't need their own price simulation when designing. Considering the throughput of the factory, the predicted number of requests is in the tens and not in the thousands.

This order of volume was brought to the attention of Rangel's IT staff, and insinuates that the methodology of communication, integration, and systems currently in place at Rangel are capable of guaranteeing smooth communication with minimal alterations.

Nonetheless, a need for choosing between different options for the architecture between all of the solutions was raised. Two alternatives, that are subsequently presented, bring their own advantages and disadvantages. In the following section, a detailed explanation of both alternative approaches is provided, as well as their positive and negative points, considering factors such as scalability, performance, security, and maintainability.

3.6.2. 1st alternative – joining of TMS outputs and create many quotes

The first alternative is one where the TMS modules for road freight and air and sea freight are accessed separately. These modules are currently separate pieces of software, as developed by the software provider. A complete specification of previously mentioned components and their interactions can be found in Figure 3.5.

In this scenario, data is received from the customer through the RCP and passed through the validation process and variable's values assignment, then that data is inserted at the same time into the TMSs that are needed (e.g.: if a shipment is determined to need both road and sea transport, it will be quoted separately for both portions), and the quote outputs proceed to be joined together before being presented to the customer.

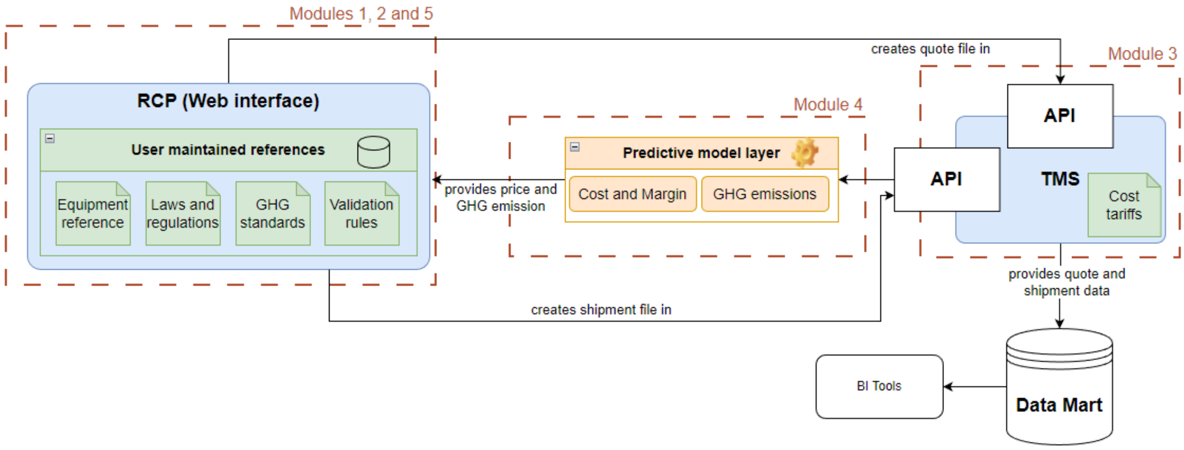

Figure 3.5. - Architecture alternative 1 - Create many quotes

The components and requirements, in this architecture, include:

- User maintained repositories of files containing reference data for equipment dimensions; reference data from laws and guidelines for all of the countries of origin and destination; GHG emission calculation standards; and tariffs previously agreed with key customers and with freight operators;
- RCC – interface for collecting inserted data, validate data quality and transport feasibility, and attribute the appropriate mode of transportation. The portal must also be able to extract complete quote data from both TMS via Application Programming Interface (API) and aggregate it in a complete proposal. This proposal, if accepted, must be adjudicated, which entails, through another API, generating a shipment entry that triggers the planning and operationalization;
- Predictive models would need to be fed, at some point, the data being provided by the client, and their predictions would need to be entered in the quote file;
- An integration process that brings quote simulation data to data marts, to be analyzed by the Business Analyst team, determining the utilization of the tool, and the number of shipments being generated, i.e., the amount of business value unlocked for Rangel.

One advantage of this approach would be that, since quotes would be inserted automatically in the TMSs for every simulation requested, we would take advantage of the integration and business processes already in place. Finally, since the independence of the quotation process from other pieces or integrations would be preserved, development work would be less intensive.

When it comes to limitations, one can find: the need to create as many quotes as simulations being requested, raising questions about maintenance of data on the TMS internal databases; the reality that predictive models are not contained as a feature in the TMS, so must receive and inject data through additional integration processes that need dedicated development; analysis and reporting are subject to the data structure and rationale of the TMS; and finally, that the operational characteristics of each TMS product may hinder the inclusion of new and more evolved features in the future, similar to what is being felt at the time of writing.

3.6.3. 2nd alternative – new quotation tool

An understanding quickly arose that the problems brought by the first, least work-intensive alternative might be undermined by using a still realistic, but ultimately more disruptive approach. Therefore, a second approach was devised that, through the creation of a new, but more powerful quoting tool, brought more flexibility to the interactions between the RCP, predictive models, and the customer.

This tool would serve as the sole platform for the creation of quotes, while also having the ability to provide price simulations without necessarily having to create a quote file in the TMS. In this context, the necessary data that came from the customer and the RCP calculations could access the tariff by itself following the same rules as the TMS, and also have integrated the predictive models inside it.

Figure 3.6 details the components of this alternative, their interactions, and how they relate to DST's requirements.

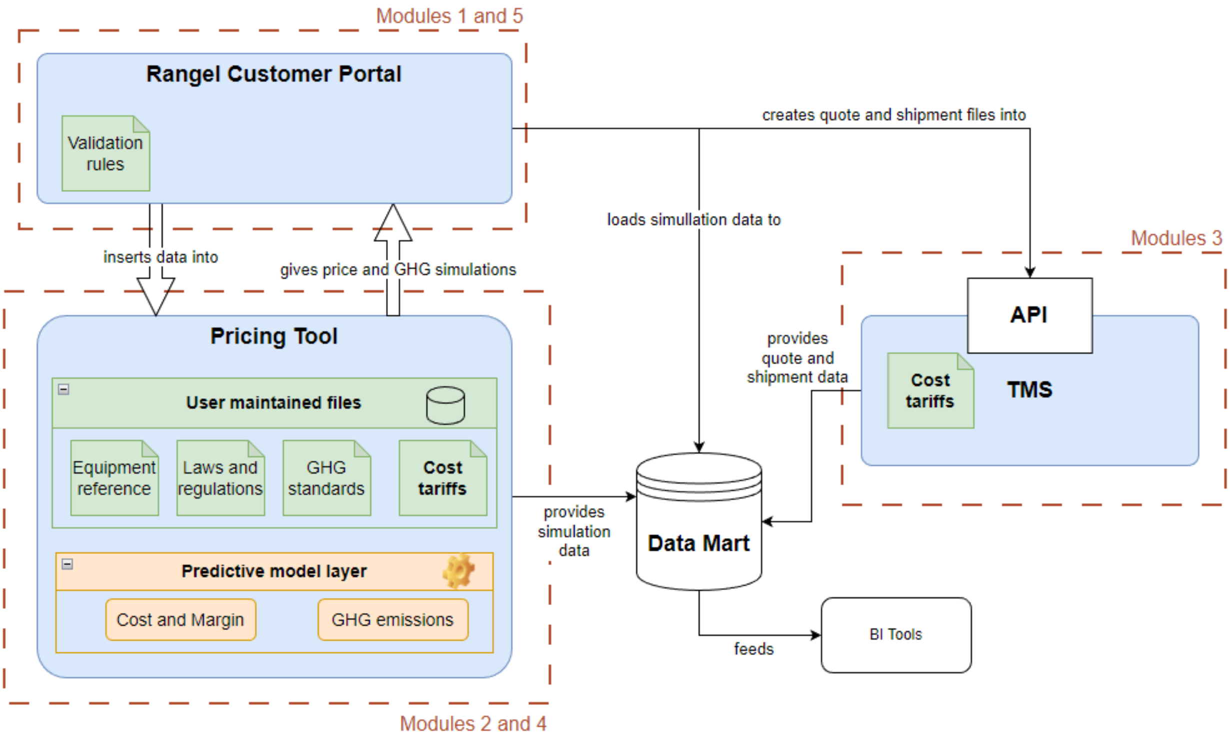

Figure 3.6. - Architecture Alternative 2 - New quotation tool

After a price is generated, assuming that it doesn't need human intervention, it would be provided to the customer by the RCP and, if accepted, only then a quote file and shipment file would be created, through API, in the corresponding TMS.

With this architecture, while minimizing the number of communications across many different software pieces, the team would need to develop, aside from the predictive models: the ETL processes; the file repositories; and the RCP's interface and validation software; and this overarching new tool, that centralizes the process through a mix of accessing tariffs and greatly complex pricing rules, provides an estimate of cost, asking price, and GHG emissions while employing predictive models.

As perks for this option's argument, were the possibility to customize pricing models based on business strategy; predictive models having ease of integration; more personalized reporting, with data designed for analytics; and most importantly obtaining control over all technological evolutions. These advantages come at the price of having to duplicate tariffs loading into two pieces – the TMS and the new tool – and the replication of complex rules in both. These, added to the more arduous and time-intensive development, could pose too significant a disadvantage for this second approach.

According to the criteria of security, both alternatives were considered similar, while the advantage in expected performance was given to the second approach, being less dependent on constant API calls to the TMS and creation and deletion of unwanted files (e.g.: avoids thousands of quotes in the TMS that are merely consultations for the design phase of construction modules). The new pricing tool approach also wins out on the criteria of maintainability and scalability since, the less dependent on the feature development and enabling of an external provider, the more flexible that development is.

At the time of writing, therefore, the option taken was to pursue the second outline alternative with a powerful new pricing tool.

CHAPTER 4

Cargo GreenQuote Hub – preparation and implementation work

With the requirements for the IT solution well established, based on the necessities that need addressing and the opportunities that can be taken advantage of, this chapter focuses on the specific conceptualization work, the conduction of the project, and the tasks done to enable and guarantee an effective implementation within deadlines. We elected to name the project as “Cargo GreenQuote Hub”.

For Rangel, the effective conjugation between the modules outlined in Chapter 3 necessitates a robust overhaul of its quotation process and its IT infrastructure. Nevertheless, this application will bring to the table several advantages, among them: the possibility for rapid communication with the client, diminishing the need for data entry and providing more quote processing capacity; the leveraging of predictive models to provide [to more potential clients] the value added service of predicted carbon emissions and costs in the most accurate manner; and the possibility of winning many high value and specialized transportation requests from prefabricated modules, improving business margins and customer loyalty.

To better explain the undertaken course for the specification and facilitation of the projects implementation, it is best to divide the discussion and the work done onto different points of view, although they occurred simultaneously: the specification of the requirements for the web interface; the centralization of regulatory and guiding information for route and equipment definition; the necessary diligences for preparing data to train the predictive models and the choice of machine learning algorithm; and finally the methodology for calculating GHG emissions.

4.1. Web interface

For the development of the web interface, which is comprised of the work modules 1 and 5, work started first by performing a thorough definition of requirements, with a business intelligence team lead, and IT staff. This encompassed

- The web interface (RCP) must be the main point of contact with a client, to gather as much of the necessary information as possible (module 1) and apply as many of the staff’s considerations as needed, as detailed in section 3.2.2;
- It should also be able to perform the computation for the optimal equipment and transport modality and determine what special requirements must be met for the operationalization to move forward (work module 2);
- It must be able to communicate that data into the systems, so a simulation of price and GHG emissions can be generated;

- Finally, it must act as the interface in which the client has the option to communicate automatically to Rangel's systems their desire to adjudicate shipments (module 5), and successively create a shipment and quote entry in the database.

Following these conversations, an enumeration of the needed fields was written, containing every datum that must be inserted in the TMS in order to create a quote, as which is provided in Table 4.1.

Table 4.1. – Field requirements for Rangel Customer Portal

Field	Mandatory?	Notes
Consignor		
Loaddress	*	At least postal code
Consignee		
Unloaddress	*	At least postal code
Loading date	*	
Unloading date	*	
Hora load		hourly windows
Hora unload		hourly windows
Packages	*	number of
Package type	*	Palletized/Volume/Not-palletized
Commodities		Free writing
Volume		Cubic
Height	*	
Width	*	
Length	*	
Gross weight	*	
Plan characteristics		Yes/No (ADR if so)
UN Number		
Additional services		Yes/No (Insurance if so)
Goods value value		In €

In collaboration with the team responsible for new developments in the RCP, the method chosen for managing this subsection of the project is the Agile framework, that breaks down deliveries into dynamic phases, or *sprints*. With fortnightly periodicity, meetings with the development team took place, to steer workload into the necessity that arise from the manufacturer, and to share difficulties faced that need help addressing. At the point of this text's writing, the front-end of the webpage has been developed and approved. This was based on the requirement evaluation that was done with the study of the current business process (section 3.2). A mockup of the developments can be seen in Appendix B.

After this sequence of deliverables was presented to management, the completion was validated. Details of this meeting's questions are provided in Appendix C.

4.2. Route and equipment attribution and validation of rules (module 2)

As explained in section 3.4, module 2 will need to evaluate if a shipment is possible, by comparing minute institutional regulations with the data inserted by customers in the RCP. It will also be the way in which the possible equipment types (e.g.: many types of containers that can fit the goods) and modalities (by road, air, or sea) for that shipment are determined.

These route and equipment attribution is made based of the rules, limits or regulations determined in section 3.2.2.:

1. Size and weight: size and weight of loads can impact not only how much space of a container (be it of truck, boat, or plane) it occupies, making transportation more expensive and carbon intensive, but also, in making it so a certain load can only be delivered by specific equipment, conditions if a loaded container can physically be moved into location. As an example, an excessively large trailer would not be able to circulate to a build site in the heart of the Lisbon downtown;
2. Date and time: very relevant in air and road transport, the time and day at which trip legs are optimal to occur are often at odds with the circulation restrictions of the travelled countries. For example, in Portugal, trucks carrying dangerous goods cannot circulate on Sundays from 7 a.m. until midnight.

Towards the end goal, a survey of the most up to date regulations on circulation and equipment was conducted, complemented by interviews with the operational team at Rangel. The results were promising, as most governments and regulatory bodies have data freely available, and many logistics service providers end up providing that information to their customers on their web pages and resources. The sources of information included, and that were compiled into in user-maintained reference files, were:

- For hours and dates of circulation restrictions, the relevant laws of the countries that are most present as loading or unloading addresses for Rangel;
- For the purposes of equipment standards, the EU's regulations for usable truck dimensions, shipping containers, and aerial containers, that serve as a basis for Rangel official web resource [39];
- For special authorization requirements for road transport, the Portuguese governments' official journal [40].

After this data gathering, cross-verification of the sources was conducted with other publicly available data and Rangel's operational team, particularly with staff responsible for custom critical transportation.

By breaking the determination of route and equipment process into phases, we can use heuristics to perform it, step by step.

1. Modality and equipment decision: With the origin and destination of the load, determine the modality of transport, i.e., if the load is to be sent by road, air, or sea. Then, decide, based on equipment capacity standards, the specific type of equipment, e.g.: truck, tractor-trailer, high cube container, etc.;
2. Optimal route decision: Fixating the optimal route, based on third-party licensed software, which takes into account the possibility of circulation of equipment decided in the previous step (i.e., doesn't consider routes where the biggest trailers can't reach, for example);
3. Feasibility decision: consider if the requested trip is possible to be done in the specified timeframe, taking into account date and time restrictions as well as the transit duration;
4. Special requirements decision: decide if the equipment from step 1 makes it necessary to provide special requirements, e.g.: dangerous goods signs, extra plaques on the back of trucks, police escorts, etc.

4.3. Predictive model for cost and price (module 4)

As previously discussed, one of the main focuses on the path to the ideal solution is the employment of predictive models, with the target variables of cost and asking price, and GHG emissions. Since the latter requires more preparation and transformation of Rangel's business processes (as stated in Section 3.2.3), the work was divided into two parts, with the prediction of cost being the first focus. This would, in the end, prove indispensable for accessing the quality of training datasets, code iterations, and identifying issues that needed tending to. Since both Rangel and DST desired to employ

INEGI's expertise in the field, the Institute would be responsible for the development of the module, with Rangel providing business logic insights and the most valuable form of datasets needed.

Through this collaboration, the intended output of this task is a machine learning algorithm that analyzes the influence of different variables enumerated in Tables 3.1 and 3.2 on the cost and price of a given shipment and proposes an asking price to the client.

4.3.1. Training data preparation

Evidently, the first step in any ML algorithm development is obtaining a dataset with quality and structure that can provide the necessary insights, as well as help define formatting and structure for integrating said algorithm into the IT architecture, in this case, of the FF (Rangel). To that end, a work component of data preparation was conducted.

Reflecting a recent change in the TMS software at the start of the current year, that changed the way in which ships were registered, the biggest number of registries that could be obtained was of more than 100000 shipments registered in the database but comprising a small date interval of January to August of 2023. Data from before this interval was available, but with such a different rationale, that it became clear that comparing between them and the current dataset was not feasible. This historical business data had to be obtained at first instance using manual user exports.

An issue arose with the default manual features of extracting data from the TMS, in that they were very limited in the data they contained, being organized in an inconvenient way for manipulation, as information from trips, shipments, and goods, all belonged to different tables, with different data grains. Since the default process of extraction did not yield sufficiently satisfactory results, in looking to arrive at a better way of gathering the needed data and allow for more complete analytics, a custom data view in the TMS was created with resort to its native query language.

Ultimately, data from four different source tables: *Trips*, *Shipments* and *Quotes*, was combined with the *Goods* source table into a new dataset that could be shared with INEGI, following the logic in the diagram of Figure 4.1.

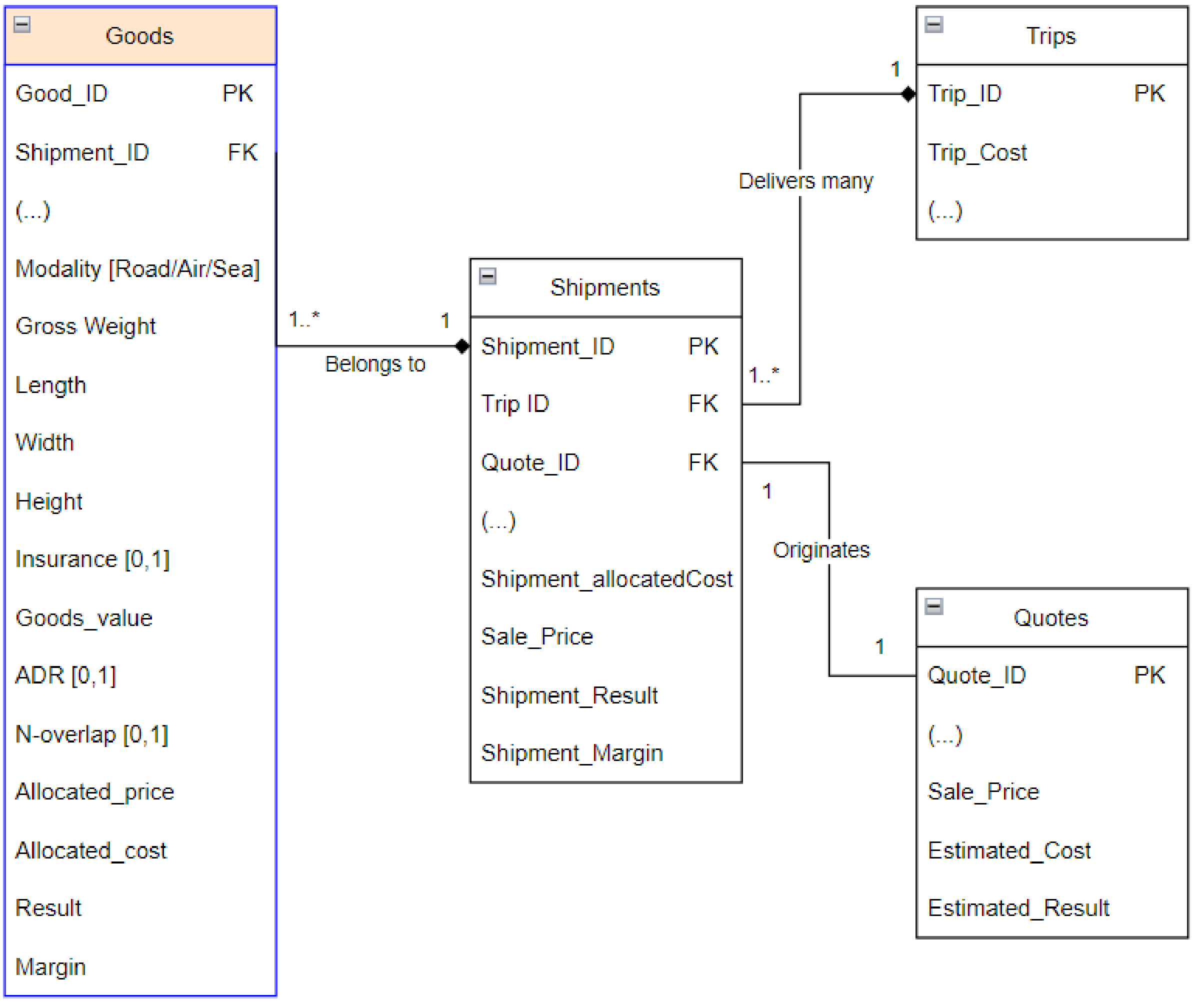

Figure 4.1 - Training dataset compilation logic

Within the requirements aforementioned, a few key variables were brought to the final format of the dataset, also outlined in Figure 4.1, specifically:

From *Goods*: table:

- Modality: determined by which part of the TMS data is extracted from;
- Insurance: binary, and set as "1" if [Additional Services] includes any insurance-specific codes;
- ADR: binary, and set as "1" if goods include any ADR component;
- N-overlap: binary and set as "1" if goods includes "Non-Overlappable" or "Non-Overlapping" component. In this case the volume is calculated by loading meters, i.e., [Height] is equal to the available height of the container;
- Allocated_price: Revenue allocation for a goods line, based on the proportion of [Chargeable Weight] of its shipments it comprised;
- Allocated_cost: Cost allocation for a goods line, based on the proportion of [Chargeable Weight] of its shipments it comprised;
- Result: Difference between [Allocated_price] and [Allocated_cost]

- Margin: Ratio between [Allocated_price] and [Result], in percentage

From *Shipments* table:

- Shipment_allocatedCost: Cost allocation for a shipment, based on the proportion of [Chargeable Weight] of its trip it comprised;
- Sale_price: directly equal to the value inserted in Quote table for that shipment
- Shipment_Result: Difference between [Sale_price] and [Shipment_allocatedCost]
- Shipment_Margin: Ratio between [Sale _price] and [Shipment _Result], in percentage

From *Quotes* table:

- Estimated_Cost: calculated by the TMS based on the current versions of standard price tariffs (for Groupage), or manually inserted if consulted with operational team – this in the current version of the quotation process, i.e., in the future this field must be predicted by ML algorithms
- Estimated_Result: Difference between [Sale_price] and [Estimated _Cost]
- Sale_Price: by default, is the product of [Estimated_Cost] and a commercial margin defined by upper management, but most of the time it is manually inserted by sales team – this in the current version of the quotation process, i.e., in the future this field must be suggested by ML algorithms

From *Trips* table:

- Trip_cost: extracted from planning module of the TMS

With the illustrated schema, all the attributes currently possible to take into consideration were gathered, as well as the target variables of Cost and Asking Price. This dataset was then provided to INEGI to begin training the prediction algorithm.

4.3.2. Choice of algorithm and results

As described in section 3.1.1, the two phases in the lifecycle of a modular construction project – Planning and Execution – entail different important points. First and foremost, levels of prediction assertiveness need not be as high in a planning or design phase as they do in the execution phase, from whence the manufacturer will actually adjudicate for the inbound and outbound shipments.

Secondly, but most important, is that since the amount of historical data of transportation of prefabricated modules does not exist, the training data will not reflect that reality very well. With that in mind, the algorithm most indicated was that of the neural network, as that would allow for transfer learning. In essence, the knowledge obtained in predicting for the transportation of regular loads can be [to a point], transposed into the outbound case, through manipulation of the architecture and performing some fine-tuning [41].

The desired results, however, were not yet up to par with the expectations and requirements of either interested party. The minimum prediction error produced was higher than the literature suggests as acceptable, so work is continuing on the dataset improvement realm.

Possible issues on the quality of data provided was brought to Rangel's attention, and a process of vetting of the historical data of the TMS was started.

4.4. Incorporation of GHG emissions

Before any improvements on integrating emissions data into databases, a standard for calculating said emissions was needed. Through investigation of standards in use for the logistics business, consideration, and discussion with Rangel's Quality Control department, it was decided that the Greenhouse Gas Protocol (GHG Protocol), as a widely recognized global accounting standard for measuring and managing GHG emissions, would be the most suited, being of not too complex implementation and of significant use throughout the market. It provides a framework for organizations to quantify and report their emissions, and it distinguishes between three scopes, with Scope 3 being the most challenging and comprehensive to assess [42].

In brief, Scope 1 Emissions are those that come directly from sources within the organization's ownership or control. Examples include leakage of refrigerant, on-site fuel combustion, and emissions from company-owned automobiles. Scope 2 Emissions are indirect emissions that come from using energy that has been purchased. These are linked to information on energy consumption, making their calculation reasonably simple [42]. Both of these scopes do not fully incorporate the need of either Rangel nor the manufacturer, since a FF does not own the equipment themselves nor do they pay directly for fuel on transport trips. Scope 3 emissions are indirect emissions that result from an organization's operations but come from sources that the business does not own or control, including the emissions of vehicles that are not owned or operated by Rangel, so these emissions can be harder to quantify [42]. Emissions, for each trip, will be calculated by multiplying the distance the shipment has traveled, times the weight of the shipment, times the transportation mode's specific emissions factor [43], with the following expression:

$$\sum \left(\begin{array}{c} quantity\ of\ goods\ sold\ [tonnes] \ \times \ distance\ travelled\ in\ transport\ legs\ [km] \\ \times \ emission\ factor\ of\ transport\ mode\ or\ vehicle\ type \end{array} \right) \tag{1}$$

Although not yet implemented, work was started to apply the GHG Protocol's methodology for calculating scope 3 emissions, currently in the process of standardizing the formulas used for their calculation, and an articulation with partner agents (who own and operate the vehicles) to provide

Rangel with GHG values. Currently, only the Air and Sea components have integrated GHG in the TMS, but this still needs to be reflected in the extracted data. The end goal is, as explained in section 3.2.3, to reflect for each trip, shipment or good that was registered in the TMS, the amount in kilograms of GHG emitted. This will allow later for a predictive model solely focused on GHG as the target variable.

CHAPTER 5

Conclusions and future work

In conclusion, this dissertation has explored the multifaceted work of the specification, design, and partial implementation of an IT solution for a Freight Forwarder's client in the modular construction sector. Through a review of existing literature, rigorous data collection and analysis, and a comprehensive examination of the methodologies and strategies used, we have uncovered valuable insights and contributed to the body of knowledge in this field. As this endeavor is concluded, it is evident that this is a dynamic and evolving domain, ripe with opportunities for further innovation. This has not only deepened our understanding but has also highlighted the areas where future work can continue to make significant contributions. In this final chapter, we reflect on the assertiveness of the encountered solution towards the client’s problem statement, discuss its implications, and outline avenues for future exploration, which ultimately underscores the relevance of the work presented.

5.1. Main conclusions

Having arrived at the conclusion of the discussion, it is correct to assume that its objectives were attained. We can assert this by looking into the validation of concepts, designs, and requirements conducted with the expert staff of the manufacturer (DST) and the decision-makers at the Freight Forwarder (Rangel). There are essentially two questions that need answering:

1. Does this solution answer the manufacturer’s need?
2. Does the specification and work so far lay out the way forward for Rangel?

To answer the first question, and get the consortium leader’s perspective, validation sessions were conducted at the end of the conceptualization phase of the project, to allow the different entities to start focused work on their proposed tasks and clearly lay out each one’s expected outcomes. As a result, among the key takeaways were that: the client needs a quick and convenient way to get price and emission simulations; restrictions for circulation and special transportation criteria need to be considered already in the design phase to investigate if producing a module with specific dimensions is economically viable; the more assertive that prediction is, the better, so there is the need to incorporate machine learning (ML) algorithms into it. That being said, across the validation interaction, which the detail of can be found in Annex D, the solution proposed was deemed to fully respond to all of the manufacturer’s worries and needs.

The second point’s corroboration should be done first for the conceptualization side and then by work module, since contributions were sometimes very distinct depending on what the business needed. Most proofs of concept had to be done with the responsible department heads at Rangel, and their inputs were greatly valued, even to add corrections throughout the process.

In first place, while performing the aforementioned work in Chapter 3, relevant contributions consisted of: systematizing the takeaways from meetings with the manufacturer when it comes to their necessities and complexity of logistics; mapping of the initial and ideal business processes using the BPMN framework, as well as interviewing business teams and management to specify impactful variables. The contributions in module 3 also came in this stage, where the decision on IT architecture was facilitated by the author by schematizing different alternatives and providing relevant criteria for decision-making.

Secondly, for modules 1 and 5, the author's work impacted the delivery by defining the business requirements, with process and field mapping, and regularly accompanying the teams' deliverables.

For module 2, and following interviews with operational and sales staff, contributions were in all of the gathering and systematization of information from different national and international standards, requirements, and regulations, that will be inserted in the new quotation system.

Regarding module 4, the creation of new datasets, by using data engineering techniques, was performed by the author in close alignment with the needs of the external partner and the restrictions from the TMS software and the business intelligence team. Even after the initial sharing of information, these tasks continued, with the search for new ways of presenting data, with corrections, simplification or categorization, and new datasets.

Lastly, the incorporation of GHG emissions necessitated a methodology that was searched for by the author, and validated with the sustainability executive of the company. Validation between the third-party service provider of the TMS software and the company's needs was also conducted, establishing a clear path forward in this realm of the work.

We can be confident, all things considered, that the author's contributions effectively addressed the needs, worries, and preferences of all parties involved in order to arrive at the best possible answer., and that the contributions of the work described in the dissertation were of considerable importance to the implementation of such a project.

5.2. Future work

With such a complex implementation pipeline, we found it best to divide the discussion on the future work for the company into the different realms in which work was conducted.

5.2.1. Rangel Customer Portal

While the request for basic information from the client is capable of enabling the front-end of the web interface, further flexibility should be allowed to said client, after the initial interaction between them and the system, such as the additional visibility, as described in Annex D. This should follow changes that the client requests, but also opportunities that the business team progressively identifies.

There is also the clear chance for the RCP to become the go-to way that clients in general ask for price quotations, which is bound to be a clear differentiation factor between Rangel and its competitors.

5.2.2. Attributing equipment and best routes

So far, the rules for attribution of the correct equipment type (vehicle, container, etc.) have been defined, but are not yet being taken into consideration. The next step would be to include this feature in the RCP, and evolve its assertiveness based on how many cases need corrections from the client or from the operational staff.

When calculating the route that a trip will take, currently, the TMS provides one alternative, based on the addresses specified for loading and unloading. This is not taking into account if, for example, a truck with certain dimensions will be able to cross all of the roads in that route. It also does not guarantee that that route is the optimal in terms of duration or if it is the one most often taken. There is, therefore, the opportunity to integrate global positioning solutions to assess, with large datasets, what the best course to take is.

5.2.3. Predicting cost and asking price

For training predictive models with the most useful data, work will continue in gathering business team's insights and integrating more data points in the dataset. More attributes of historical shipments and quotes need to be provided, and a uniformization of data structures of pre-TMS and post-TMS implementation will likely take place, broadening the sample size to an expected 400% the current amount of training dataset size.

5.2.4. Predicting GHG emissions

As has been discussed in Section 4.4, the confirmation of the Scope 3 GHG emissions is being done by the responsible department and upper management, so that, with data from the weight and distance of trips, we will be able to assign to shipments the amount of GHG emitted. These facts will need to be provided in a training dataset so that we can move forward with the predictions of GHG emissions in the new quotation tool.

5.2.5. IT architecture and Business Intelligence

For all the functionalities exposed in Chapters 3 and 4 to be well implemented, guaranteeing the stated criteria of scalability, performance, security, and maintainability, the focus on enabling the correct IT architecture must never falter. That said, the Agile methodology will be used to keep priorities straight within the development and business teams, the project managers, and the client.

Some key components must be assured, such as: the availability of the TMS service provider's APIs for creating quotes in their road, air, and sea systems; the construction of ETL processes to gather data relating to quote simulations into the data mart and, from there, to the cubes and dashboards for business analytics.

Future work must guarantee that, from this collaborative but mainly internal investment of capital and human resources, revenue is being generated as a result of the simulations proposed by the manufacturer (in the case study at hand), or by any other potential clients.

Ultimately, we hope that this text emphasizes the importance of designing innovative digital solutions in order to help solve the most complex of problems: identifying what we all must do to better with our resources, in the name of the economy and the environment.

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APPENDIX A

Summary of interviews on the current quotation process

Participants involved: Author, two Sales representatives, Operational geographic team lead, Business Intelligence team lead, Country Manager.

Objectives of the interactions: gather full knowledge of the business process of quotation; BPMN modelling of the process; identify all relevant variables; identify staffs' pain points; assess management's perception of difficulties.

Methodology: Semi-structured interviews with open-ended and detailed questioning, and shadowing for aid with TMS interaction

Key takeaways from Sales and Operational staff:

- Q1. Could you take me through the normal steps that go into getting a quote? From your point of view, what does the procedure typically involve?
- Q2. What are the primary difficulties or barriers you encounter when carrying out this procedure? Could you list any common bottlenecks that you know of?

Key takeaways from Business Intelligence team lead:

- Q1. What crucial elements, in your opinion, affect the precision or caliber of the results produced?
- Q2. Are there any typical mistakes or inconsistencies that happen while a quotation is being carried out? What do you think is the root of these problems?

Key takeaways from Country Manager:

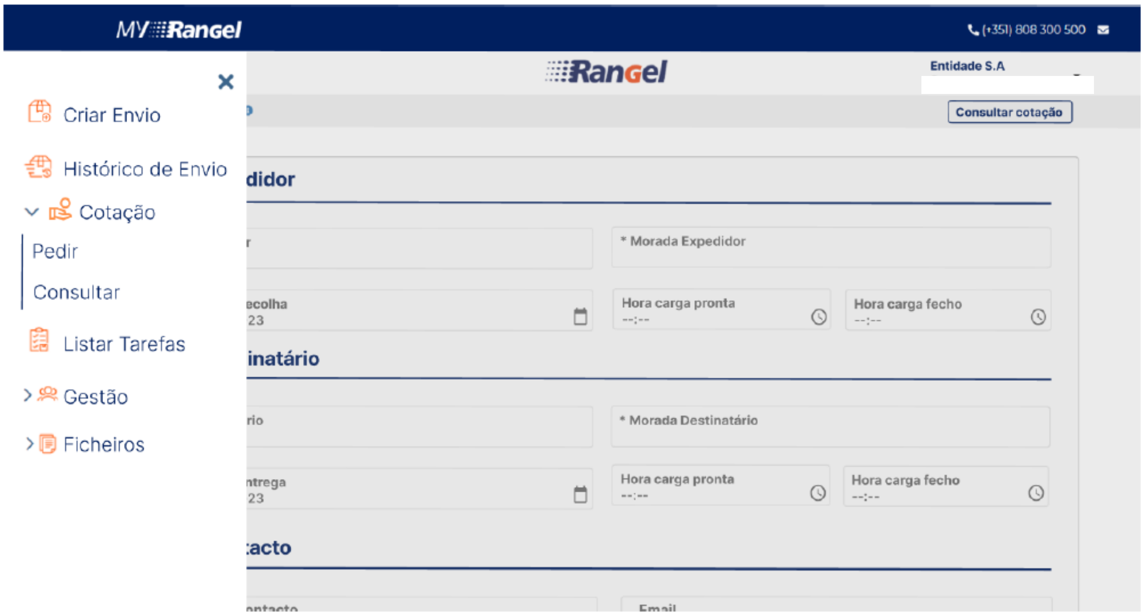
- Q1. In your experience, what are the critical factors influencing the quality or accuracy of the outcomes from this process?
- Q2. What priority do you think overhauling the price giving process has in the business well-being?

The answers and outcomes of these interviews and shadowing are the basis for the discussion of section 3.2.

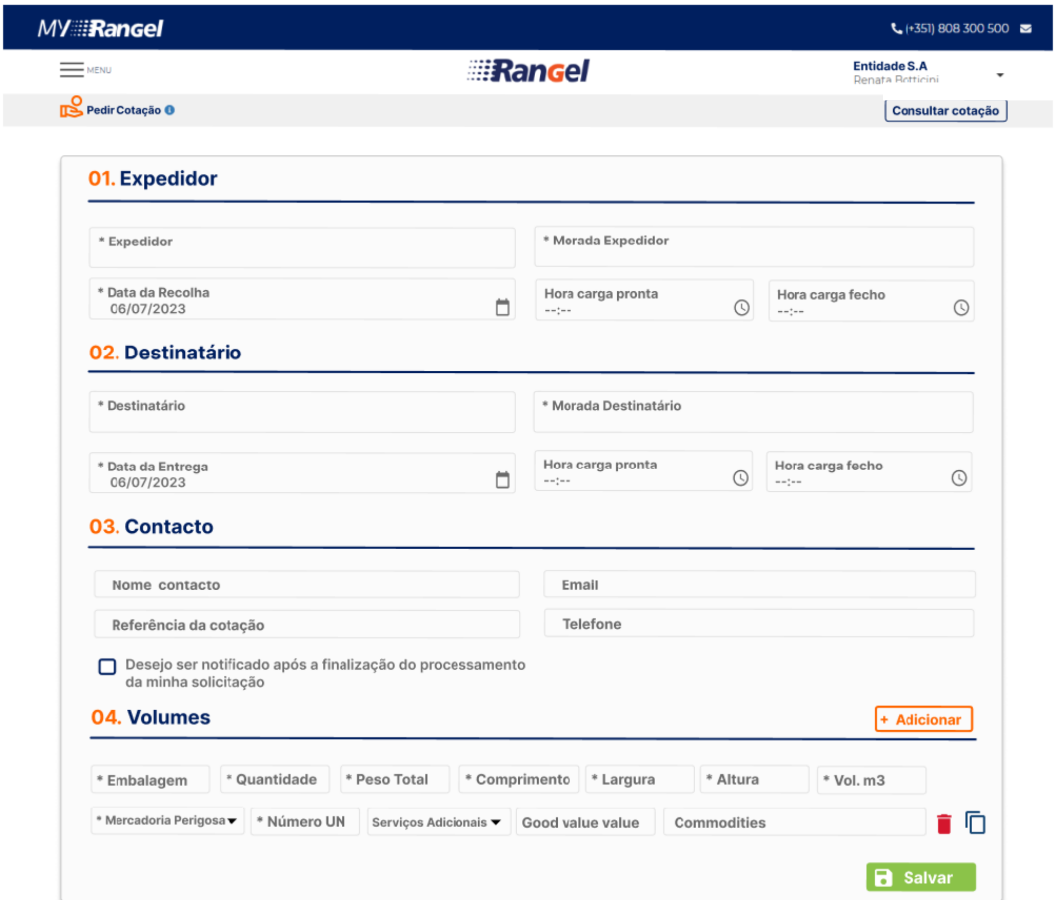
APPENDIX B

Rangel Customer Portal mockup

Screen 1: Access new “Quotes” menus

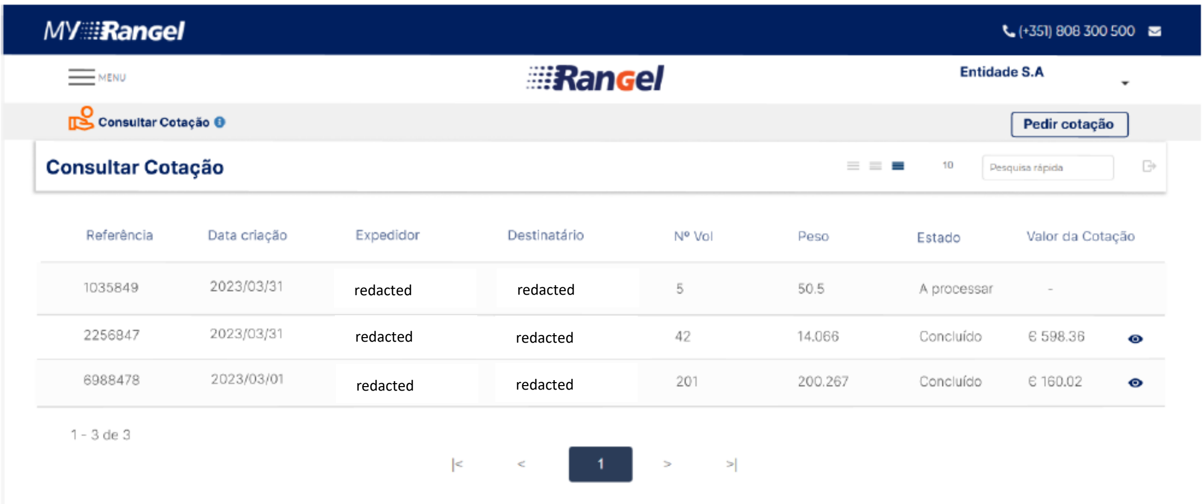


Screen 2: Ask for Quotation

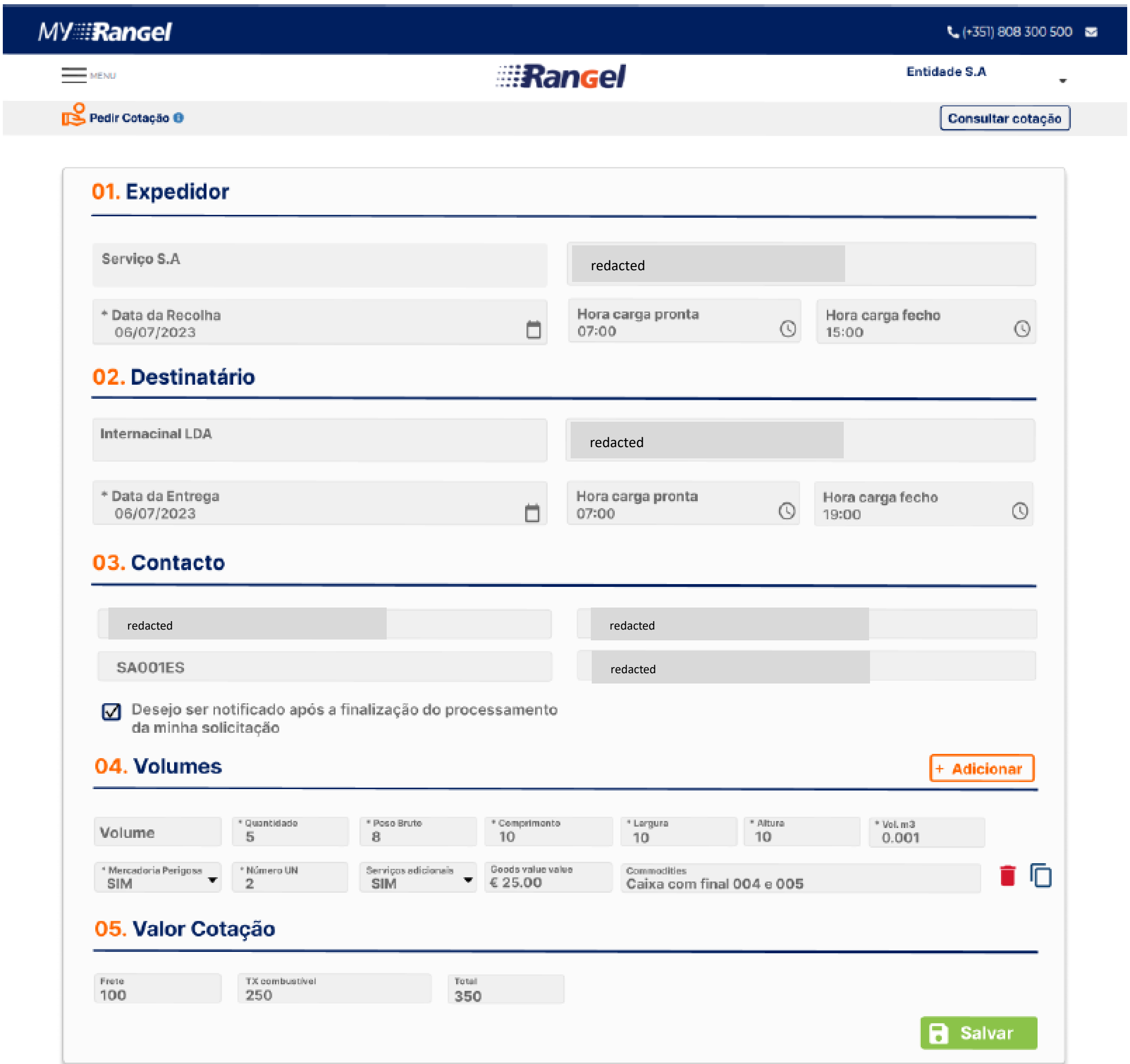


Screen 3: Successful creation

Screen 4: Check past Quotes



Screen 5: Quote detail [not realistic values]



APPENDIX C

Summary of interviews on validating Modules 1 & 5

Participants involved: Author, RCP Team lead, Business Intelligence team lead, IT team lead

Objectives of the interactions: assess whether the first mockup of the RCP's screens are a good representation of the need to ask information; gather if the RCP can be now spread to the general case for quotation processes

Methodology: Semi-structured interaction, with Author presentation of solution, and open-ended discussion

Key questions and takeaways: [answers are a compound of interventions from all stakeholders present]

Q1. How do you perceive the importance of this interface in achieving our objectives for the modular construction consortium?

A: It is essential, as it's already a way in which we communicate with established customers, and where they already have the know-how to interact with our systems.

Q2. Are there any additional functionalities or modifications you would like to see to enhance its effectiveness?

A: Appears to be in line with what was defined for function, and the mockup in line with the graphical identity of the rest of the Portal, so no further modifications as of yet.

Q3. Do you think that, as-is, the new functionality in the RCP can be disseminated to the general public?

A: Generally, yes, and clients should be incentivized to use it, in order to reduce the number of e-mails handled by sales staff, and increase responsiveness, hopefully closing a lot more deals, previously lost due to long response times.

Q4. Are there any reservations or concerns you have regarding the integration or implementation of integrations/new systems, in the future?

A: Since the RCP is a fully Rangel-owned system, new features for it are not hard to implement. Nonetheless, work on creating the new pricing tool would have to start, to secure independence from third-party software providers.

Q5. Adding to that, are there any upcoming changes or developments in your department that might affect the relevance or usage of the RCP for quotations?

A: Not currently. It's the will of management and of everyone involved that this feature becomes our future way of doing things.

APPENDIX D

Summary of interaction for validation with client

Participants involved: Author, Project Management team lead, Business Intelligence team lead, IT team lead, Client's representatives

Objectives of the interactions: assess whether the conceptualized version of Cargo GreenQuote Hub was able to satisfy consortium's project objectives, as well as future client needs, update on the state of development of Cargo GreenQuote Hub.

Methodology: Structured interaction with Author presentation of solution and state of affairs

Key questions and takeaways:

Q1. How do you perceive the purpose or utility of Cargo GreenQuote Hub within the wider consortium Work Package?

A: What was presented as a solution, fulfills this step towards the conclusion of the Package.

Q2. How do you think the mocked-up interface enhances or detracts from the overall user experience?

A: As long as the equipment and route attribution happen off-screen, this is acceptable, but would be a nice-to-have. Most, if not all, of transport trips won't be of dangerous goods, so this might be adding unnecessary complexity.

Q3. Are there any additional functionalities or modifications you'd like to see in the end-product to enhance its effectiveness?

A: With the integration into the larger consortium's digital collaborative environment, there will probably be more requirements defined, but not as of now.

Q4. Compared to similar solutions or features you've encountered, how does Cargo GreenQuote Hub measure up?

A: There are no other solutions in the market like what was presented.

Q5. What do you think sets it apart from other similar functionalities available in the market?

A: Usage of dynamic pricing with ML models is not generally used by freight forwarders, integration with customer and described ease of simulations is also not a general practice in the current landscape.

Q6. Looking ahead, how do you foresee this being integrated into your future project plans?

A: Difficult to pre-determine with what ease it will be integrated into the digital environment in development, but in the future, those will be addressed, when this solution is implemented.

APPENDIX E

Concept definitions

ADR – Accord Dangereux Routier (European Agreement concerning the International Carriage of Dangerous Goods by Road)

Asking Price – the price at which a good or service is offered for sale

Chargeable Weight – maximum value between gross weight and volume weight

Data mart – a subset of a data warehouse focused on a particular line of business, department, or subject area

ETL – Extract, Transform, and Load – the process of combining data from multiple sources into a large, central repository designated as a data warehouse

INCOTERM – International Commercial Terms - specify who is responsible for paying for and managing the shipment, insurance, documentation, customs clearance, and other activities [44]

Quote – proposal by a FF to a potential customer, listing the price for a specific shipment

Shipment – a set of goods, transported from one location to another

Trip – a transport operation carrying goods from one location to another

Volume Weight – product of volume value and gross cubic meters