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Optimization of fleets and their Propulsive alternatives by operating under Motorways of the Sea conditions

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The introduction

- The progressive **alleviation** of the **protectionist** attitude of the European policy towards the **maritime transport.**
- The European Institutions have **transfered the responsability** of the multimodal transport is competitive by its own means **to the private initiative**.
- In many ocassions studies try to find **the most suitable route for the features of the transport mode** when the approach should be the opposite: the features of the transport means should be adapted to the transport service requirements.
- The most of the studies about vessel prototypes adapted to SSS **do not evaluate** their operation acording the results achieved by the multimodal chains (**'door to door'services**)

There is not much quantitative knowledge about the combined influence of fleet features, cargo units and the selection of the sea motorway on the competitiveness of the multimodal 'door to door' transport

Motivation and the main target

- Despite of the efforts made by the administrations the **expected success** for the establishment of the sea motorways **has not been reached**. An example of this is the case of **Vigo-St.Nazaire**

The establishment of an analysis and decision method which allows the selection of the optimal maritime route, the technical and operational characterization of the fleet and the identification of the most suitable cargo unit for the maximization of the competitive advantage of multimodal routes generated through the sea motorway selected, against the alternative of road transport.

The Method and sub-objectives

Step I:The opportunity assessment

- To establish the qualitative assessment of the rationality of the operation of a sea motorway according to the framework.

Step II:The acceptability analysis

- To identify rigorously the optimal maritime route for the establishment of a sea motorway defining the constraints for the utility of the objective functions.
- To identify the most influential variables on the competitiveness of multimodal routes.

Step III: The feasibility analysis

- To develop a mathematical model able to characterize the required resources : the fleet and cargo units

Quantification of results: *The assessment model for the case of France-Spain*

Bilateral Agreement **between Spain and France in 2006 to promote the development of Motorways of the Sea by linking up their respective Atlantic coastlines ('The declaration of intentions about the Motorways of the Sea')**

The requirements are:

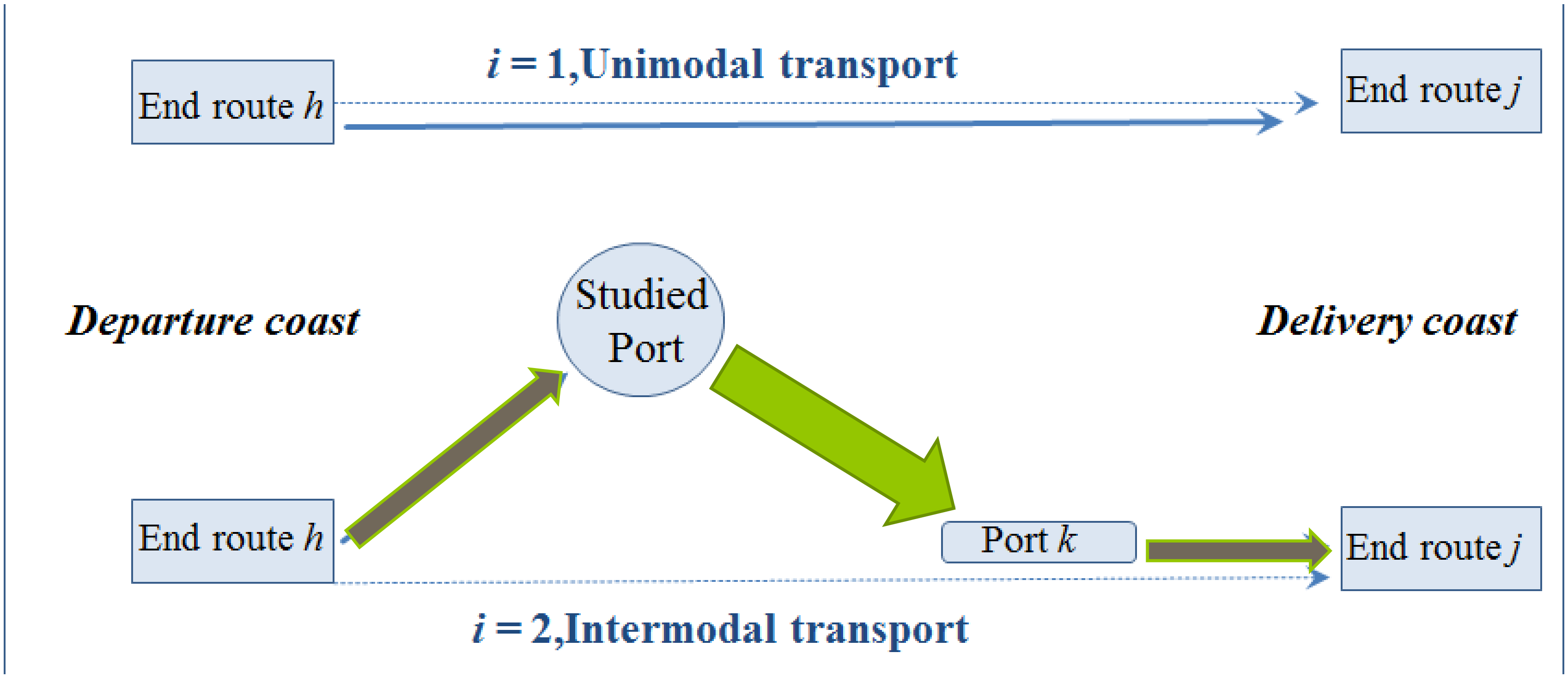
i) a service frequency of at least 4 departures per week each way during the first two years of operation;
ii) a frequency of at least 7 departures per week each way once these 2 years have elapsed;
iii) annual traffic of at least 350,000 semi-trailers should have been reached at the end of 5 years;
v) it should have risen to 850,000 after 10 years.

From the evaluation of the framework in the stage I

- The most important uncontrollable variables which determine the competitiveness of multimodal routes have been identified(SR, DR).
- Controllable variables which should be defined by the transport company have been also identified:
  - Kind of vessel $\boldsymbol{TB_q}$ kind and amount of cargo capacity of vessels $\bar{G}$, manoeuvre means ***MM*** and cargo handling system ***MG***, Speed of the vessels ***VB*** and number of the vessels ***NB***, number of trips per vessels, **NT**, and the age of vessels **Eg**
- The objective functions have been qualitatively defined.
- Constraints to main and auxiliary variables.
- Expressions which relate main variables and auxiliary variables.
- Alternatives of fleets and routes have been suggested in a first approach in this stage.

Articulation of the routes for the study

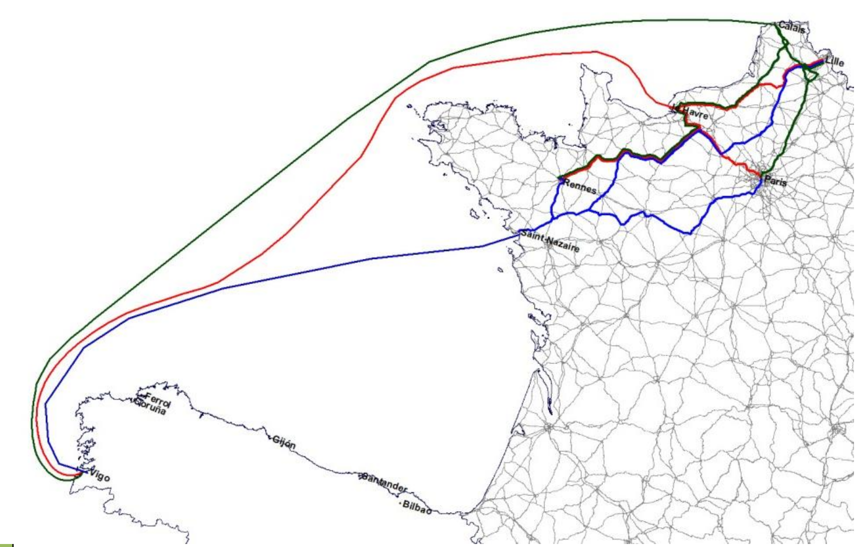
- Approach to a distribution net as a 'Comodity problem' with 'hubs' and deterministic and finite nodes.
- 'Many to many' model which can be simplified to a model 'one to many' (Hall, 1989,Daganzo 1994).



Stage II: the aceptability analysis

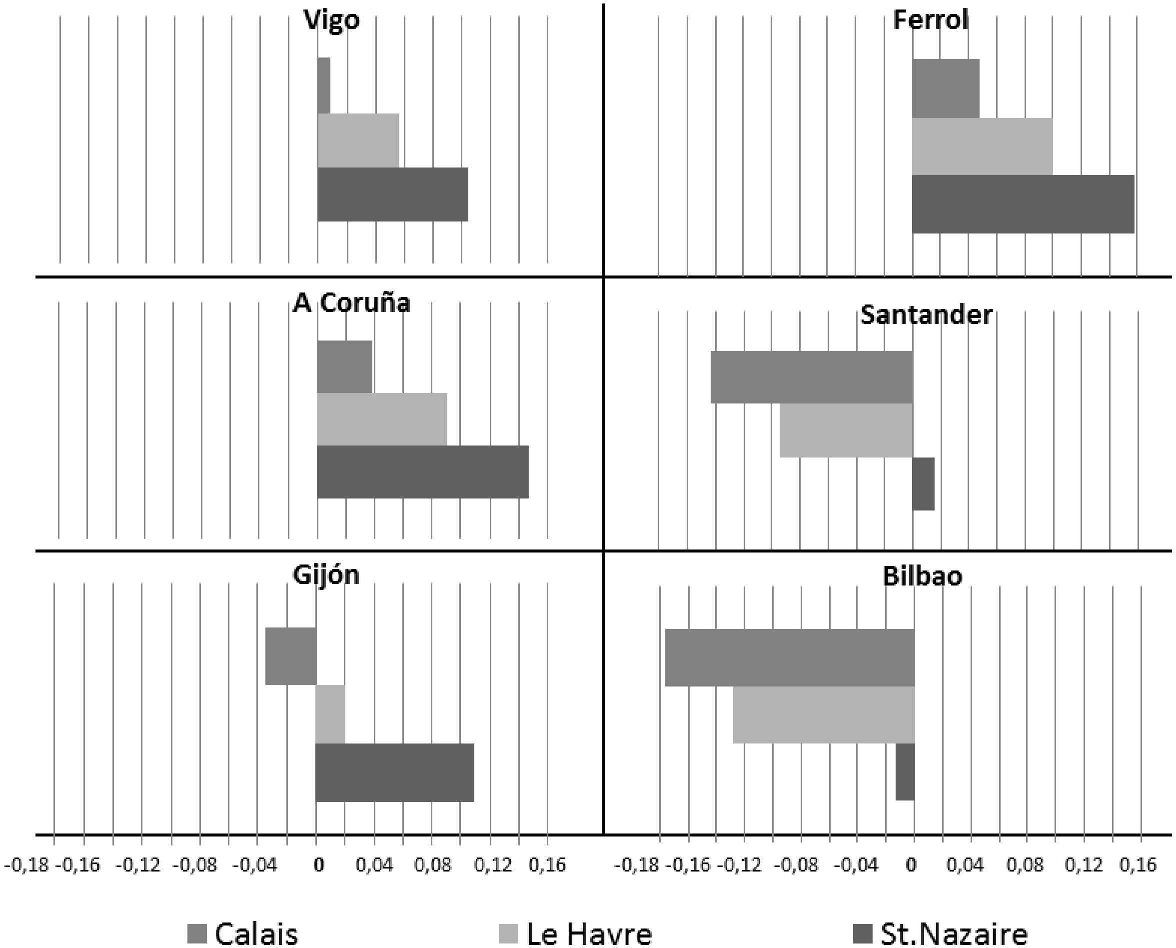
Methodology proposed to quantify the results.

Articulation of the routes of the study

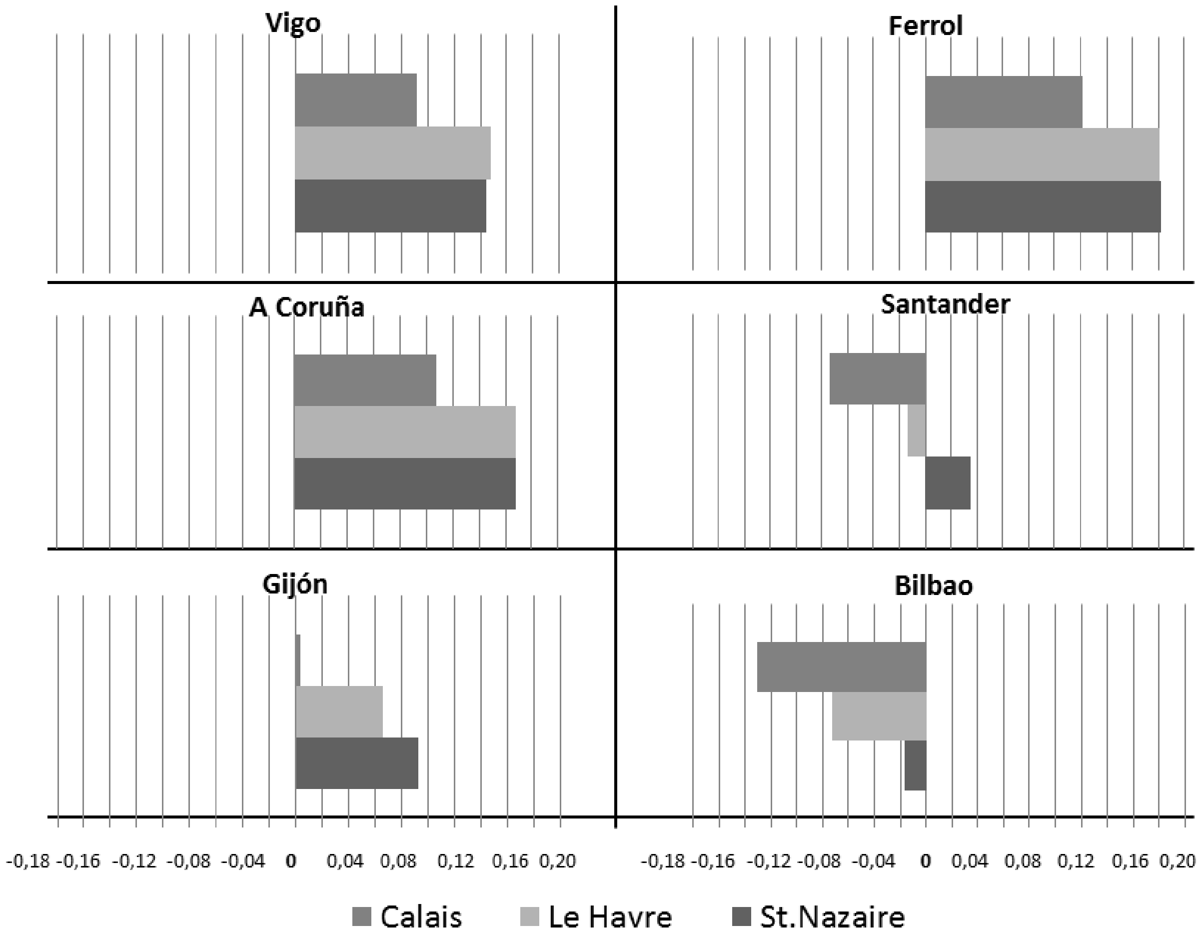


Spanish Ports	French Ports	D_k (Km)	French city	d_j (Km)
Vigo	Calais	1390	Rennes	1453
	St. Nazaire	915	Paris	1577
	Le Havre	1232	Lille	1793
Ferrol	Calais	1206	Rennes	1412
	St. Nazaire	717	Paris	1553
	Le Havre	1049	Lille	1751
Coruña	Calais	1225	Rennes	1392
	St. Nazaire	735	Paris	1514
	Le Havre	1067	Lille	1731
Gijón	Calais	1138	Rennes	1061
	St. Nazaire	563	Paris	1184
	Le Havre	980	Lille	1400
Santander	Calais	1164	Rennes	892
	St. Nazaire	508	Paris	1015
	Le Havre	1006	Lille	1231
Bilbao	Calais	1206	Rennes	795
	St. Nazaire	522	Paris	917
	Le Havre	1049	Lille	1134

Methodology proposed to quantify the results. Evaluation of the possible maritime routes for each port considered. Spain.



Methodology proposed to quantify the results. Evaluation of the possible maritime routes for each port considered. Spain.

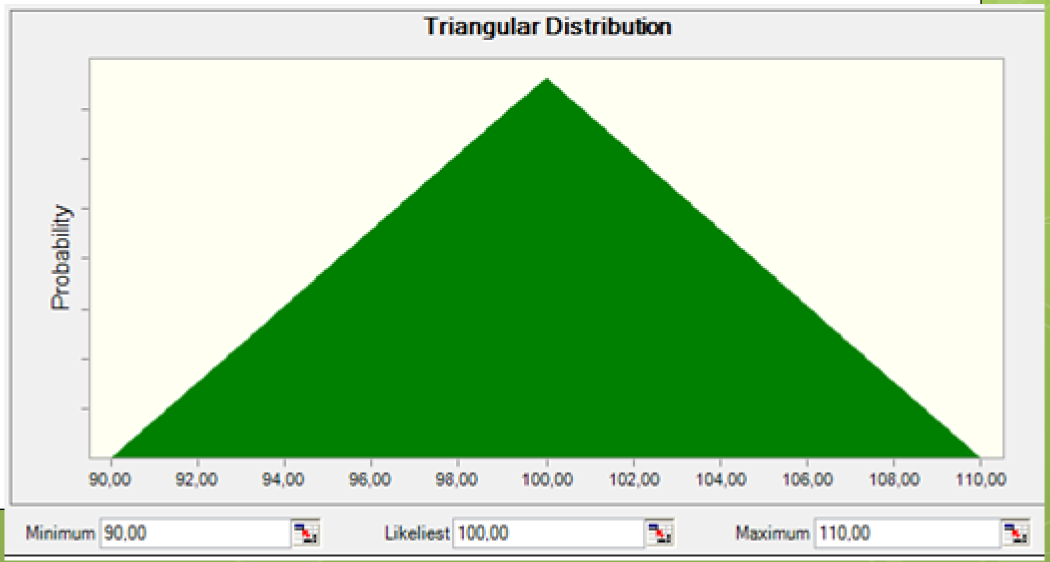


Time and cost

- The most interesting French port : **St.Nazaire**
- The most interesting Spanish ports: **Ferrol, A Coruña y Vigo**

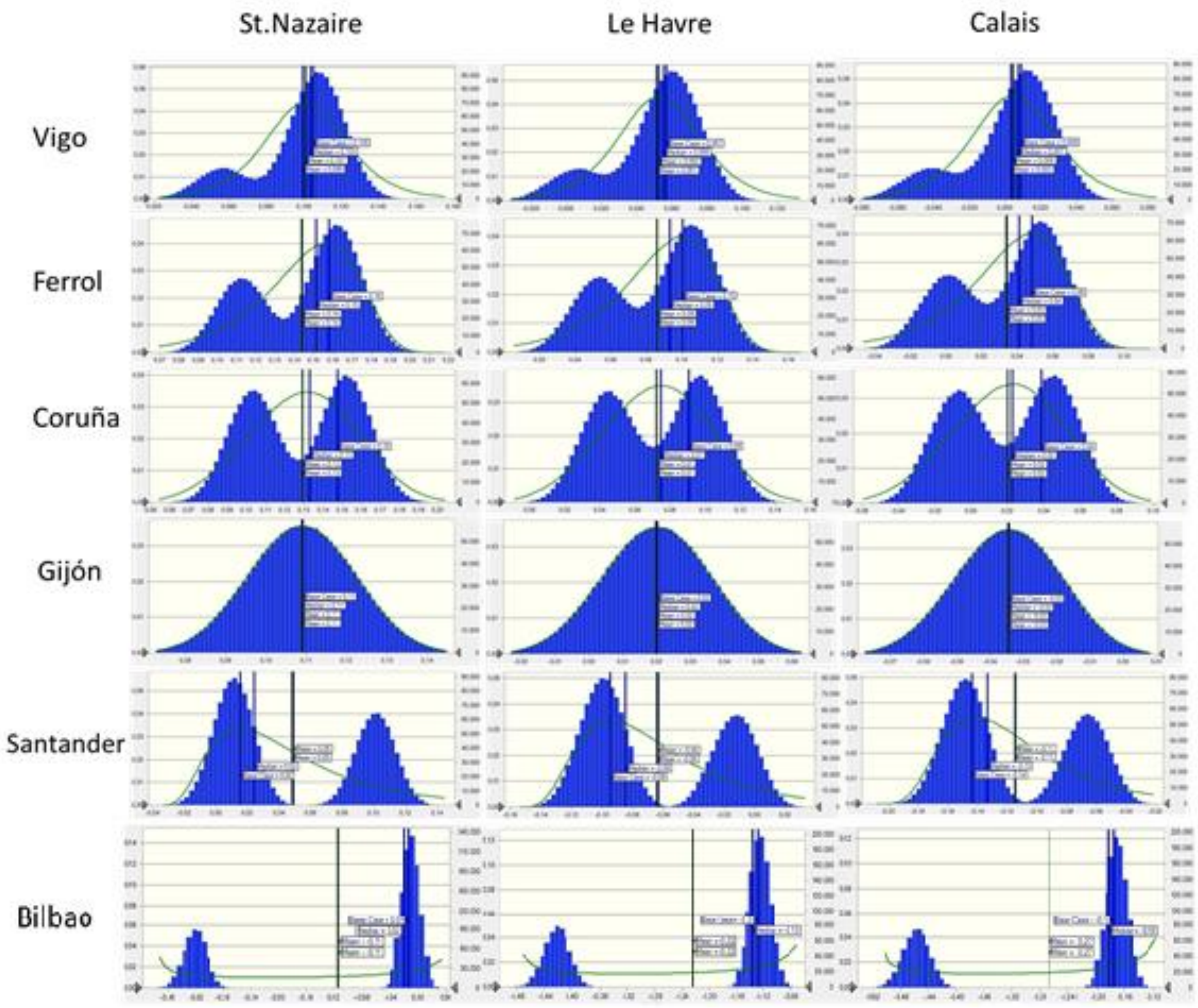
The risk assessment and the sensitivity analysis for the routes

- Multi Criteria decision matrix built with information taken from different authors (implies mistakes).
- Assessment of past scenarios based on values known (risk) but their variations and the implications of them are not met yet (uncertainty level).
- Monte Carlo simulations. Assuming triangular distributions (20% of base), 1.600.000 trials.
- The risk assessment: the goodness level of the port indexes as estimators of the distributions obtained.



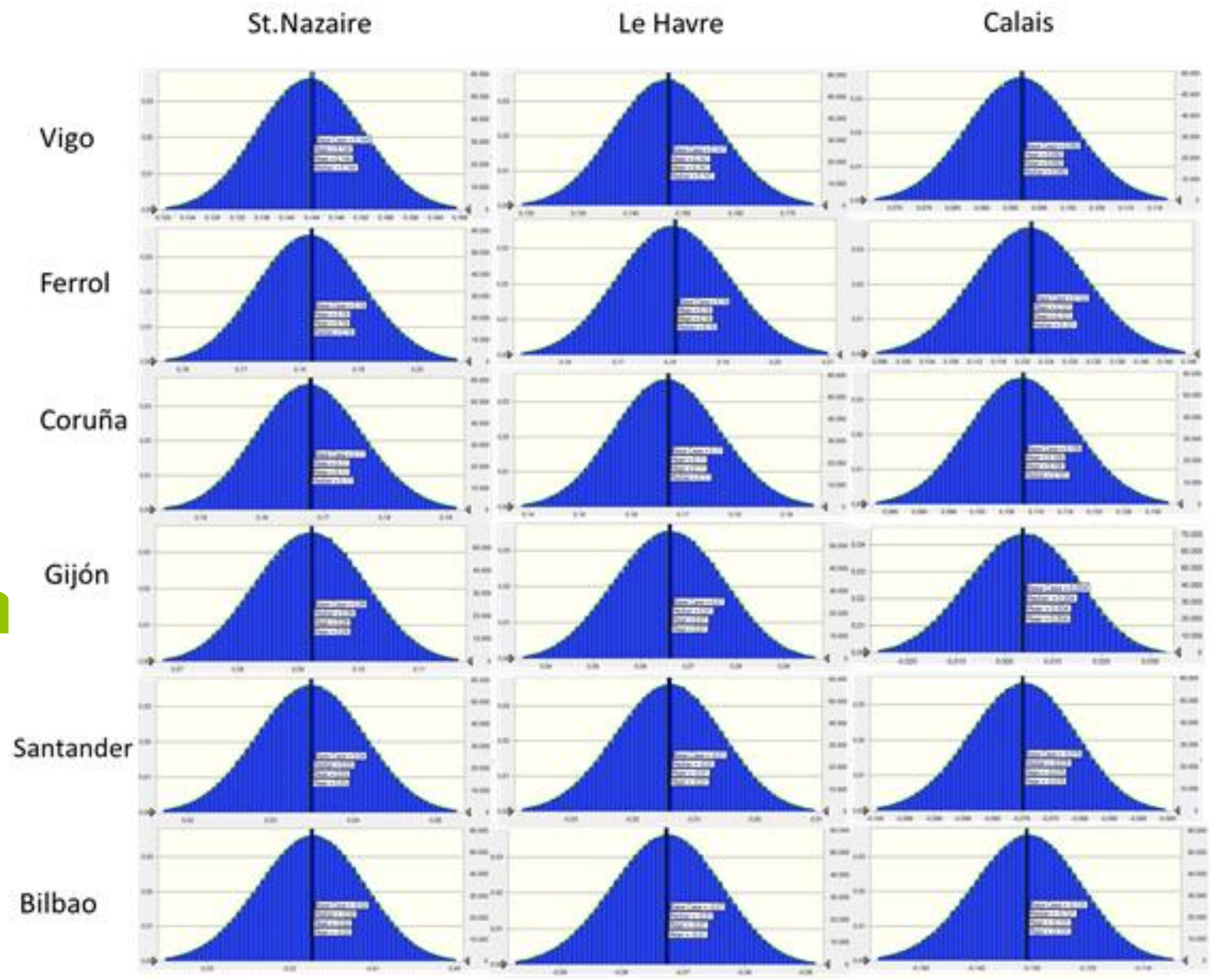
Stage II: the aceptability analysis

The risk assessment and the sensitivity analysis for the routes in terms of the time: IDP^{T}k



Stage II: the aceptability analysis

The risk assessment and the sensitivity analysis for the routes in terms of the cost: IPT^{C}_{k}



The risk assessment and the sensitivity analysis for the routes in terms of the cost : IPT^C_k

Quantitative analysis of the cost index :

Ferrol-St.Nazaire
Ferrol-Le Havre
A Coruña-St.Nazaire
A Coruña-Le Havre
Vigo-St.Nazaire
Vigo-Le Havre
Gijón-St.Nazaire

The risk assessment for the cost index:

Every routes with positive cost indexes

The sensitivity of cost indexes to no controllable variables:

Every routes with positive cost indexes

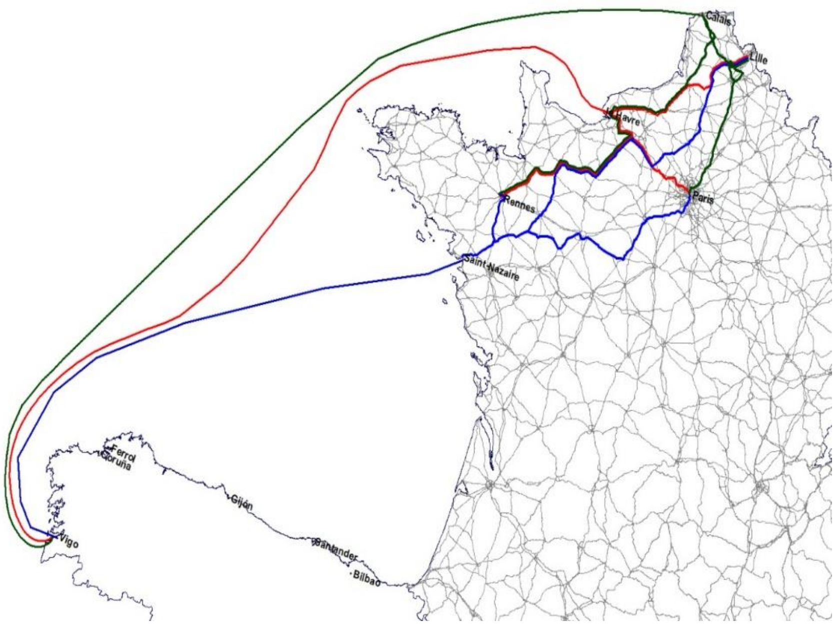
According the analysis of cost index:

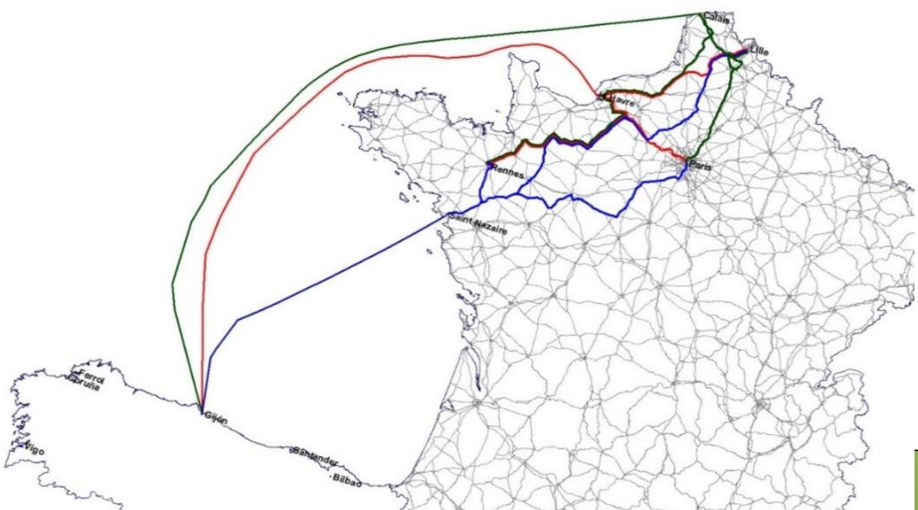
Ferrol-St.Nazaire
Ferrol-Le Havre
A Coruña-St.Nazaire
A Coruña-Le Havre
Vigo-St.Nazaire → $IPT^C_k =$ **0,14**
Vigo-Le Havre
Gijón-St.Nazaire → $IPT^C_k =$ **0,09**

The Problem

- **Vigo-St.Nazaire (2009):**Acciona-Transmediterranea Shipping Company (it was not operative)

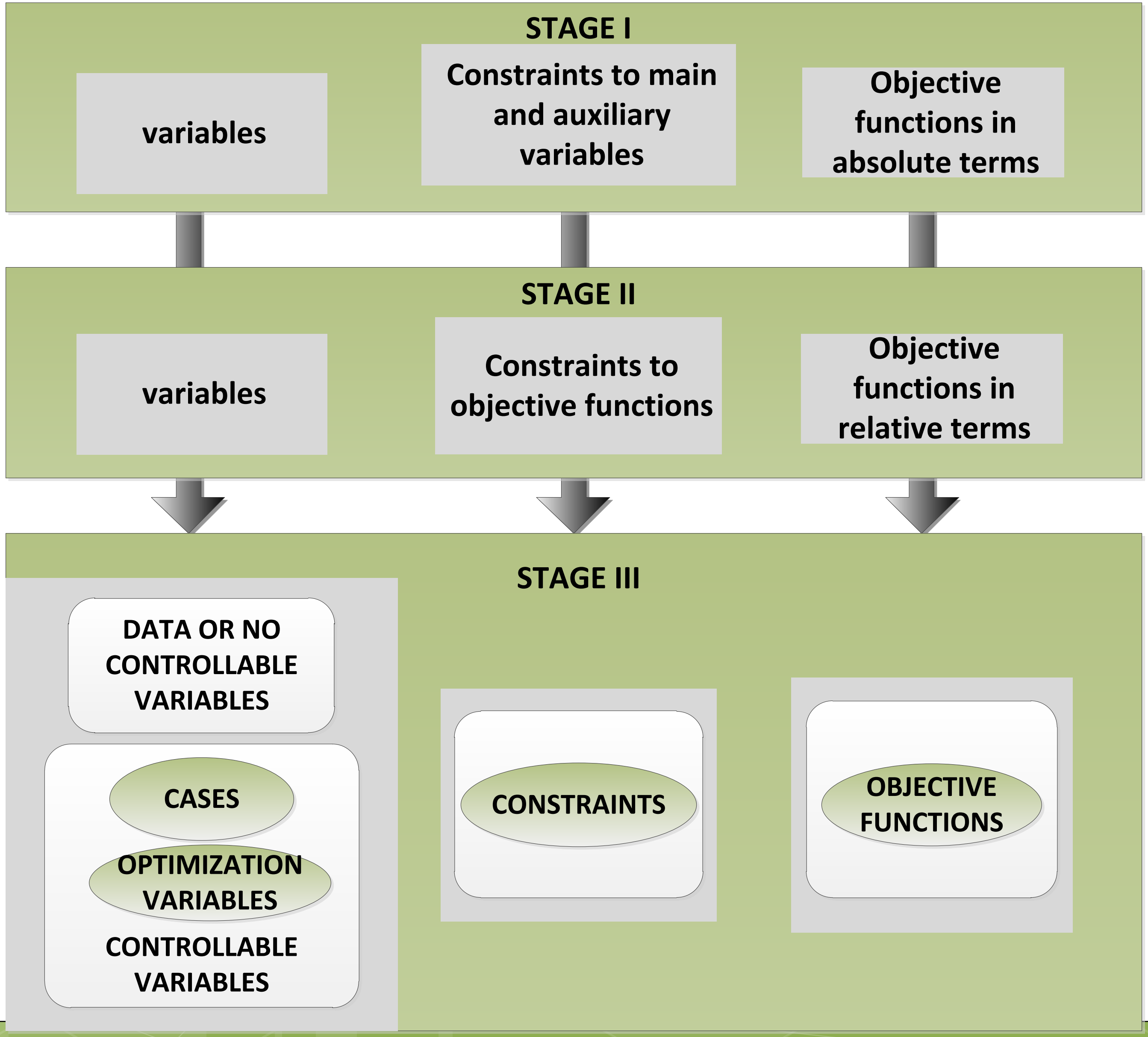
- **Gijón-St.Nazaire (2010):** GLD Atlantic Shipping Company (Successfull operation):Gijón, in comparison to Vigo, moves less general cargo annually (**587,401t vs 2,607,037t**) and fewer containers (**175,016 vs1,582,047 units in 2009**),



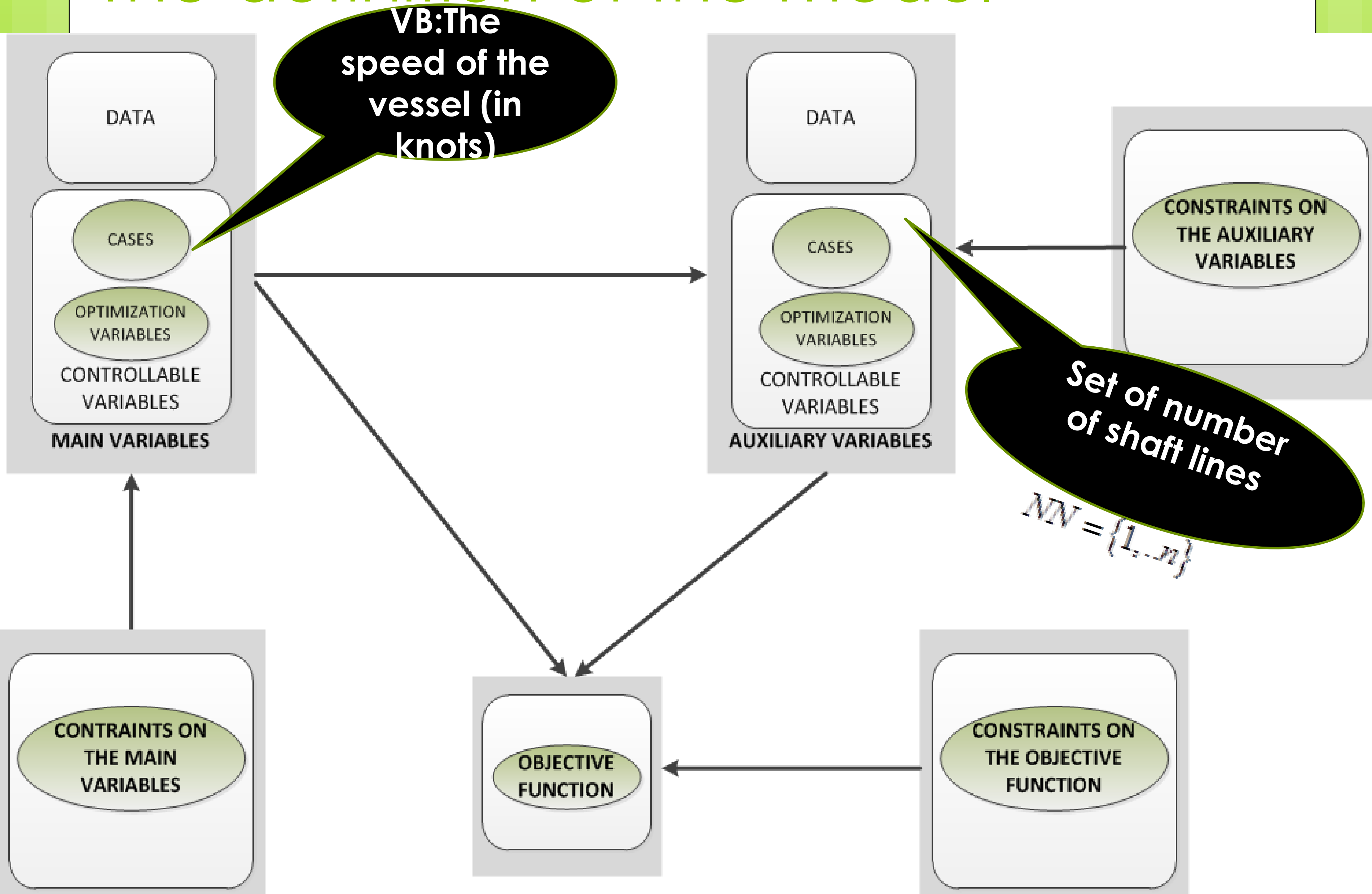


THE KEY (according to the Port Authorities):**<u>the necessary number of vessels</u>** for the fleet to cope with the requirements of cargo units and minimum frequency demanded by the Agreement (the same for both cases): 2 vessels for Gijón-St.Nazaire and 3 for Vigo-St.Nazaire

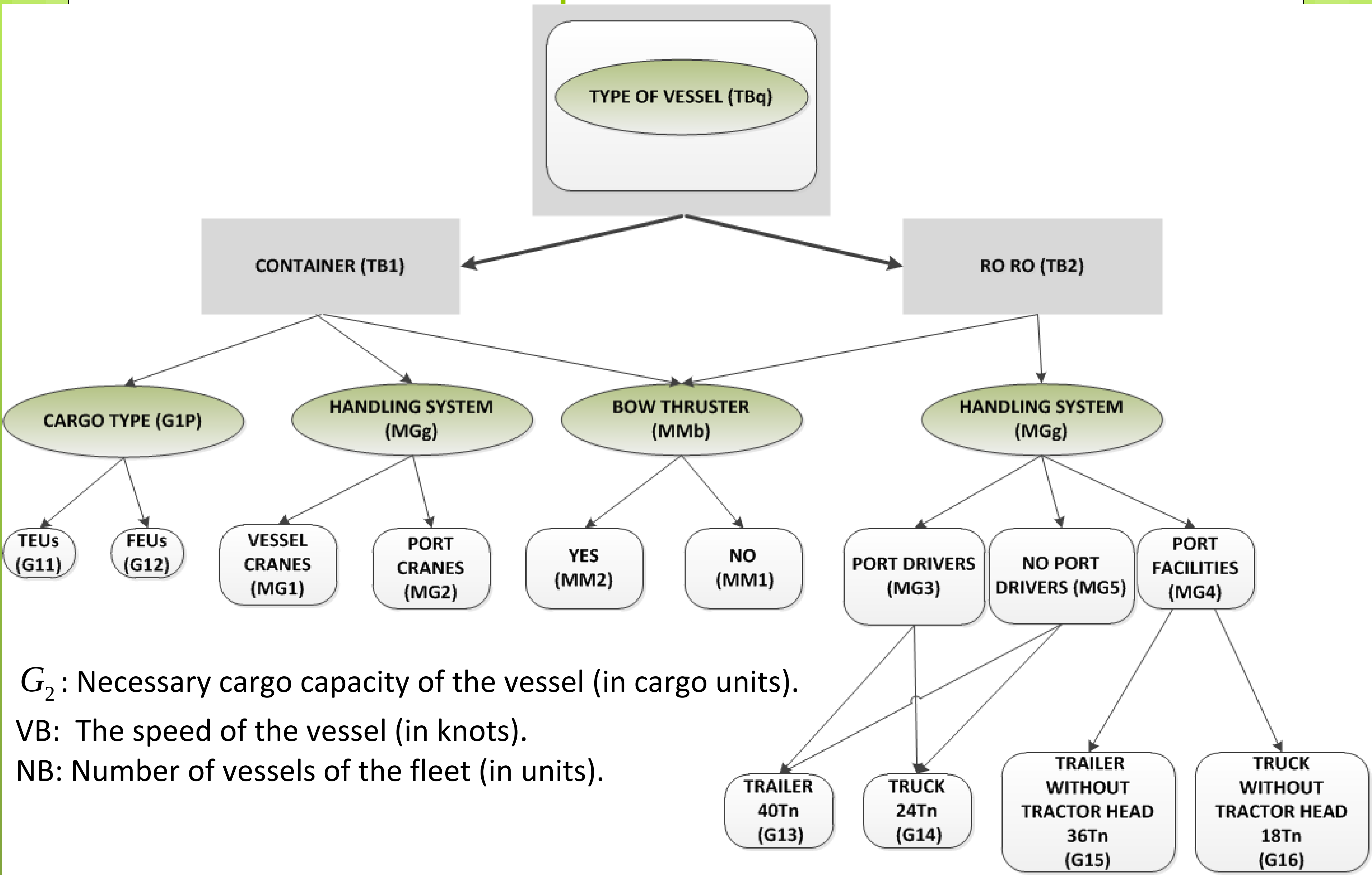
Stage III: the feasibility analysis



The definition of the model



Variables of the problem: Main variables

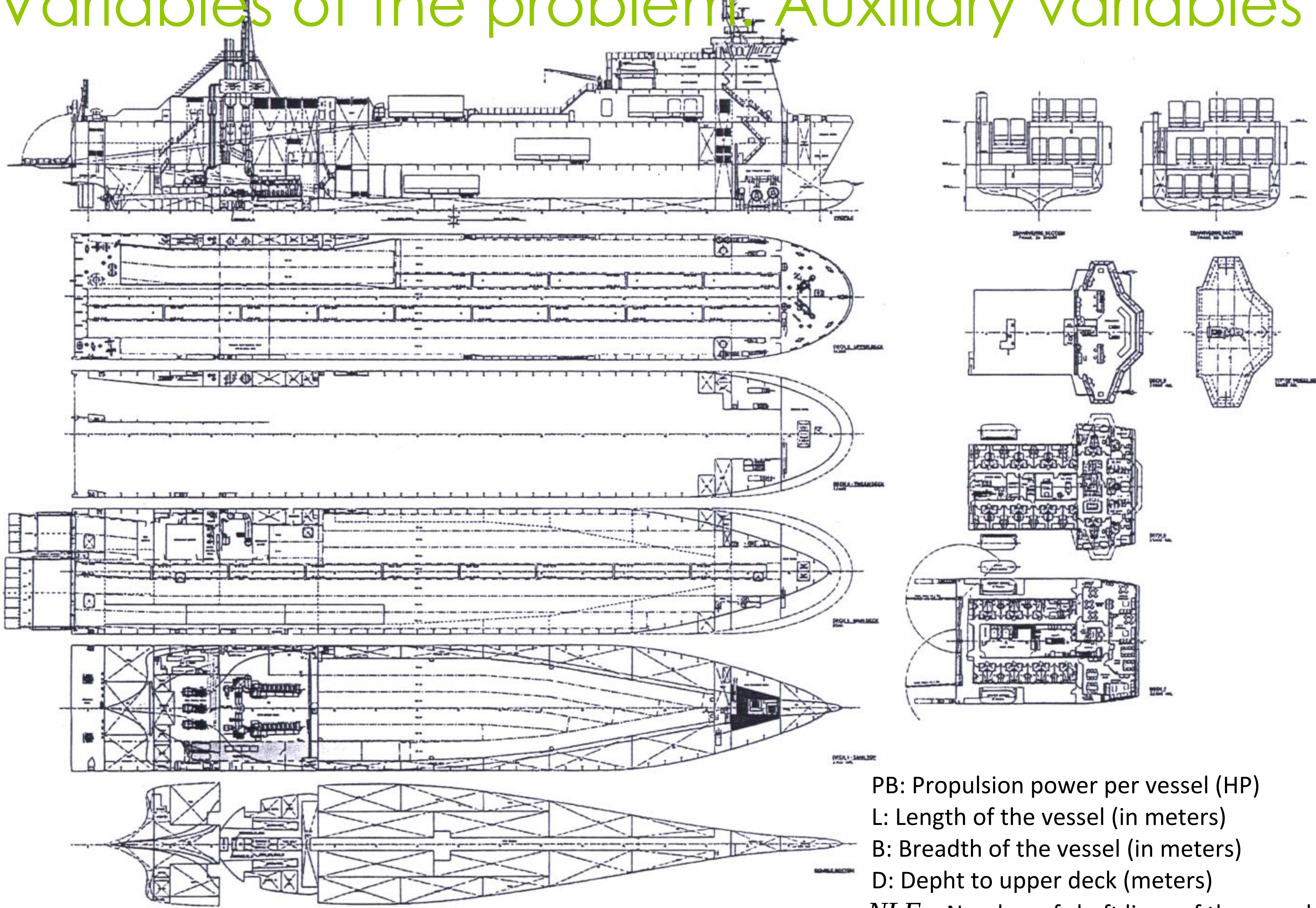


G_2 : Necessary cargo capacity of the vessel (in cargo units).

VB: The speed of the vessel (in knots).

NB: Number of vessels of the fleet (in units).

Variables of the problem: Auxiliary variables



PB: Propulsion power per vessel (HP)
L: Length of the vessel (in meters)
B: Breadth of the vessel (in meters)
D: Depht to upper deck (meters)
NLE_n : Number of shaft lines of the vessel.

Elements of the model. **Constraints to auxiliary variables.**

- Constraints due to dimensional ratios and to the port requirements (identified in the stage I)
- Requirements of the available space in engine rooms.
- Compliance with the minimum freebord (Protocol of 1988 relating to the international convention on load lines, 1966 with all their amendments (MSC 270 (85)): $FB > FBm$
- Meeting (dimensionally)with the cargo needs required

Elements of the model. **Constraints to main variables.**

- $VB<(3.7\times\nabla^{0.1667}/0.154)$
- (BOE n°165 , 11st July 2007 and BOE N°175, 23rd July 2007): 85.000 trucks without tractor head per year.
- Convention demands 4 departures per week and direction during the first two years and then 7 departures per week and direction.

  $$740\approx 672\geq N\geq 384;$$

- One daily departure of a vessel in each direction:

  $$TVB\leq NB\times 12$$

Elements of the model.**Objective functions and their constraints.**

- Objective functions: the maximization of the difference in terms of the time and cost between unimodal and multimodal transport (Siu J. et al.,2010). They were already identified in the stage I.

- The interest of the load owner in the multimodal chain is based on the relative advantage in terms of the cost and time provided by this transport system versus the road (port indexes in terms of the time and cost calculated in the stage II).

$F_1 = \max (CU-CMU)$ $\qquad$ $(CU-CMU)/(CMU_+CU) \geq 0.14$

$F_2 = \max (TVU-TVM);$ $\qquad$ $(TVU-TVM)/(TVM+TVU) \geq 0.10$

Calculation of objective functions. **Functions of costs.**

- Cost of **road** transport ('*Observatory of road freight transport costs*')

$$CU=\left(\frac{C_{4,p}}{P_p}\right)\times\left(\sum_{Z=1}^{3}\sum_{d=1}^{3}(Xz\times Xd\times DRazd)\right) \quad \text{para} \quad p=1,\dots 6$$

- Cost of **multimodal** transport:

$$CMU=CMU_{1,1}+CMU_{1,2}+\mathbf{CMU_2}$$

→ Minimum freight required 'Break Even' Gross Margin=0 (Pereira F. et al.,2007, etc.)

$$CMU_{1,1}=\left(\frac{C_{4,p}}{P_p}\right)\times\left(\sum_{d=1}^{3}(Xd\times DRbz_d)\right) \quad \text{para} \quad p=1,\dots 6$$

$$CMU_{1,2}=\left(\frac{C_{4,p}}{P_p}\right)\times\left(\sum_{Z=1}^{3}(Xz\times DRbz_d)\right) \quad \text{para} \quad p=1,\dots 6$$

Calculation of objective functions. **Functions of costs.**

- Cost of maritime transport (Pardo M.,2009):

$$CMU_2 = \left(\frac{1}{G_3 \times Pp \times N}\right) \times \left(\sum_{C=1}^{12} (CTc)\right)$$

- **Capital** costs:
  - Amortization CT_1
  - Interests CT_2
- **Direct** fixed costs:
  - Insurance CT_3
  - Maintenance CT_4
  - Crew CT_5
- **Variable** costs:
  - Combustible CT_6
  - Dockage due CT_7
  - Cargo dues CT_8
  - Pilotage dues CT_9
  - Towing dues CT_{10}
  - Mooring dues CT_{11}
  - Loading/unloading dues CT_{12}

Calculation of the objective functions. **Function in terms of the time.**

- Time invested in the road transport integrates **the limitation of the speed** :Council Directive 92/24/EEC y 92/6/EEC and the **minimum breaks during the driving** and the maximum driving hours per day (Regulation (EC) No 561/2006). Continuous traffic flow has been assumed(Aparicio F. et al,2008).

$$
\text{TVU} = \sum_{z=1}^{3}\sum_{d=1}^{3}\left(\text{Xz} \times \text{X}_{\text{d}} \times \left[E\left[\frac{E\left(\frac{\text{DR}^{\text{a}}{}_{\text{zd}}}{9 \times V_3}\right) \times 0.75 + \frac{\text{DR}^{\text{a}}{}_{\text{zd}}}{V_3}}{9}\right] \times 24 + \left[\left(\frac{E\left(\frac{\text{DR}^{\text{a}}{}_{\text{zd}}}{9 \times V_3}\right) \times 0.75 + \frac{\text{DR}^{\text{a}}{}_{\text{zd}}}{V_3}}{9}\right) - E\left[\frac{E\left(\frac{\text{DR}^{\text{a}}{}_{\text{zd}}}{9 \times V_3}\right) \times 0.75 + \frac{\text{DR}^{\text{a}}{}_{\text{zd}}}{V_3}}{9}\right]\right] \times 9\right]\right)
$$

Calculation of the objective functions. **Functions of times.**

- Time invested in the **multimodal** transport

$$TVM = TVC_1 + TVC_2 + \boldsymbol{TVB}$$

Maritime stretch (continuous transit)

TVB_1

Loading/unloading

Amount of cargo units (G_2)

Kind of cargo units G_{1p}

Cargo handling system MG_g

TVB_2

Berthing time

$TVB_3 = TVB_{3,1} + TVB_{3,2}$

Obligation to use port pilot f(GT)

Royal Decree 393/1996 , 1st of March, article 4

Use of Towing service f(L,MMb)

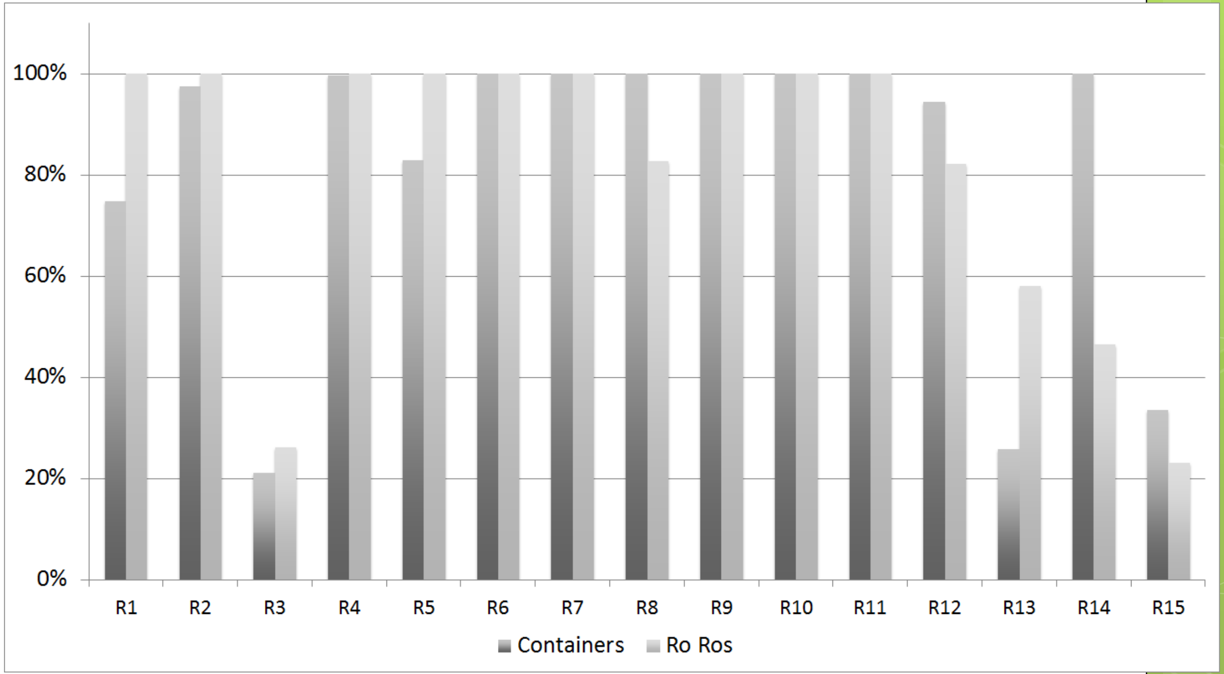
Ministry of public works

In summary: Stage III

- The variables, objective functions and restriccions identified in the previous stages have been integrated in a mathematical model able to be optimized.
- All the necesary relationships to link the auxiliary variables and the main ones to the objective functions (**more of 150**) have been established.
- This model finally allows to identifing the non-dependent variables of the model:
- **VB=speed of the vessel**
- **G_2 = amount of cargo units per vessel;**
- **NB= number of vessels of the fleet;**
- **G_{1p}= kind of cargo units;**
- **MM = maneuver means;**
- **MG = cargo handling system;**
- **TB_q=kind of vessel;**
- **E_e =age of the vessels;**

Optimization method used. **Difficulty level to find valid solutions**

Restrictions	Description
R1	T < 10
R2	FB > Fbm
R3	NC o NV >= G2
R4	Minimum B
R5	Minimum D for container vessels
R6	L/B
R7	B/D
R8	L/D
R9	B/T
R10	740≥N ≥384
R11	VB<(3,7×∇^0,1667 /0,514)
R12	Minimum G2×N
R13	(TVU-TVM)/(TVM+TVU) ≥ 0,10
R14	(CU-CMU)/(CMU+CU)≥0,14
R15	TVB≤NB×12



Less than 30% of all solutions meet the restrictions imposed. **Ro-ros** generate chains more competitive **in time** and the **container vessels in cost.**

Optimization methods used

The problem:
Discrete and continuous parameters, it is non lineal and multi objective problem which handles lineal and non lineal restrictions

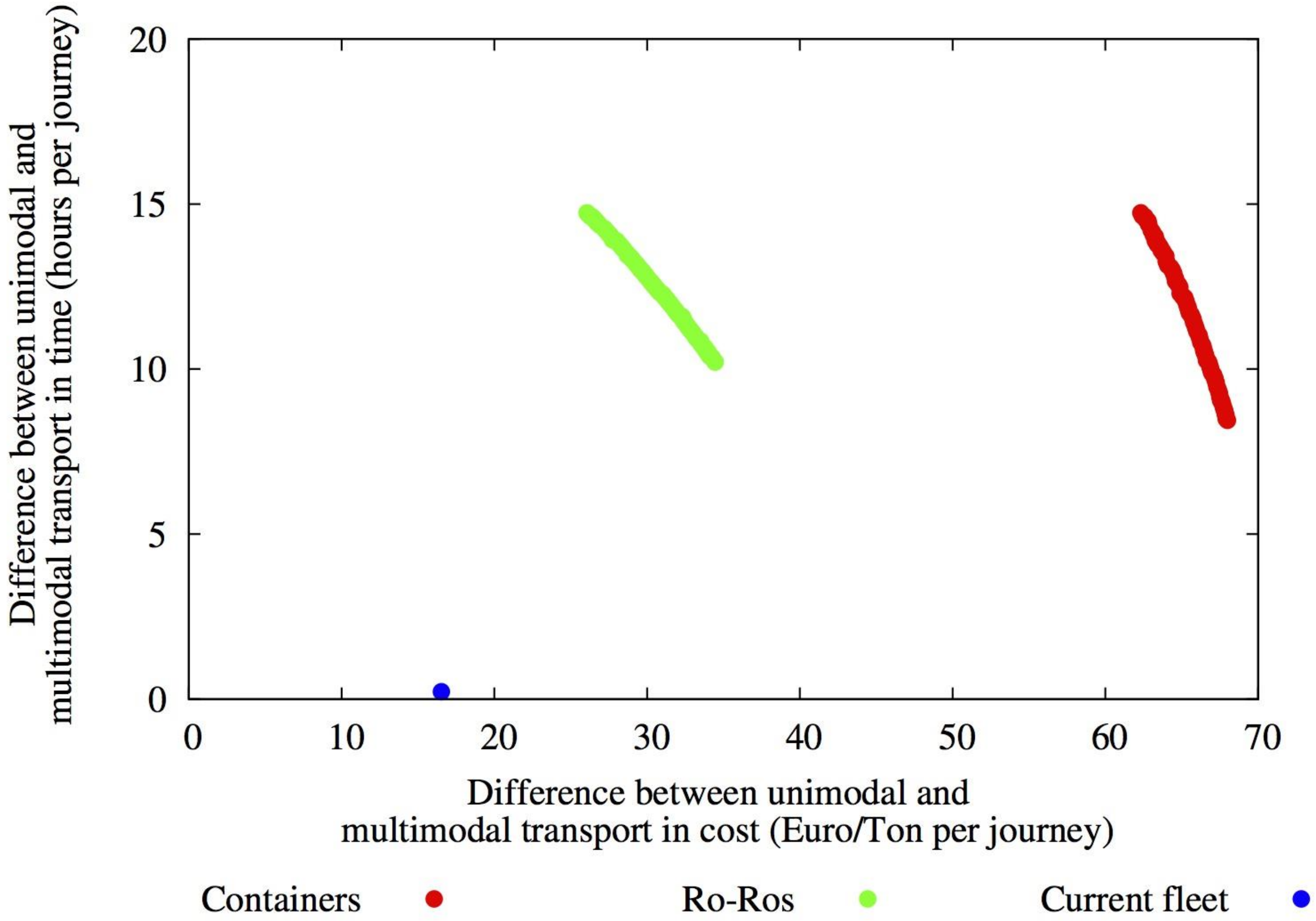
Difficulty to find feasible solutions

Evolutionary algorithms:
Exploration in various directions of the search space works well with discontinuous functions and it has alternatives for handling non linear constraints

Evolutionary strategy (mono-objetive algorithm):
Differential Evolution

Genetic algorithm (multi-objetive):
NSGA-II

Results obtained from the optimization process for intermodal chains through the Mos: Vigo-St.Nazaire



Results

The port Authorities <u>were right</u> about the necessary number of vessels, but the competitiveness results are more favourable to the Maritime route selected as optimum: Vigo-St.Nazaire

Features of the vessels obtained as best solutions for multimodal chains through Vigo-St.Nazaire and Gijon-St.Nazaire

Route	Vigo-St.Nazaire		Gijon-St.Nazaire
Kind of vessel	Container (TB1)	Ro-ro (TB2)	Ro-ro (TB2)
Kind of cargo unit	TEUs (G_{11})	Truck w/o tractor head (G_{16})	Truck w/o tractor head (G_{16})
Amount of cargo (G_2)	210	162	153
Vessel speed (Kn)	19.19	23.71	24.25
Age of the vessels	14	14	14
Bow thruster	No (MM_1)	Yes (MM_2)	Yes (MM_2)
Cargo handling system	Port cranes (MG_2)	Port facilities (MG_4)	Port facilities (MG_4)
Number of vessels (NB)	**3**	**3**	**2**
Yearly trips (N)	740	740	740
L (m)	82.04	123.91	120.92
B (m)	15.00	21.74	22.20
D to upper deck (m)	7.59	13.63	13.56
GT (Ton)	2743	9977	9967
Kind of propeller	Conventional screw (TP_1)	Conventional screw (TP_1)	Conventional screw (TP_1)
Shaft lines	1 (NLE_1)	2 (NLE_2)	2 (NLE_2)
Kind of main engine	Diesel Engine (TMP_1)	Diesel Engine (TMP_1)	Diesel Engine (TMP_1)
Main engines	1 (NMP_1)	4 (NMP_4)	4 (NMP_4)
Competitiveness results			
F_1 (€/Ton per travel)	**68.10**	**34.51**	**19.62**
F_2 (h per travel)	**8.39**	**10.18**	**2.04**

Interesting finding

- There are numerous studies about the relative competitiveness of the multimodal transport through short sea shipping against the road.
- Most of them take the vessels as a rigid input, usally ro-ro fleets mainly due to:

The approach to the problem: a possible change in the service of the current linear fleet

A forecast based on the shipping companies will prefer that the trucks become clients instead of competitors

Many occasions the analysis tries to adapt the feasibility of the routes to the available fleet

Additions to the model: new demands from the society involves new challenges

- **The 'green label' of the MoS is currently under discussion; even though it is broadly accepted that Short Sea Shipping (SSS) is more environmental friendly than other transport modes in terms of CO_2 emissions the analysis is not so favourable when NO_x, SO_2 and PM emissions are taken into account .**
- **This is especially evident when smaller and fast container vessels, the most suitable ones for MoS because they will even generate higher emissions per tonne and kilometre**
- **The model was widened to evaluate the best option of fleet, vessels, routes and cargo units by observing this concern as well**

First Step:
Introduction to a new objective function **F3** to evaluate the environmental competitiveness between transport modes

Second Step:
Inclusion of additional optimization variables (cases) regarding **the kind of propulsion plant, its abatement systems and its combustibles**

First Step: Introduction to a new objective function **F3**

$$F3 = \max(RE - MUE)$$

RE: external costs of the unimodal transport

MUE: external costs of the intermodal transport

- The environmental pollutants evaluated are: $\mathbf{SO_2}$ (acidifying substances), $\mathbf{NO_x}$ (ozone precursors) and $\mathbf{PM_{2.5}}$ (particular matter mass), moreover, $\mathbf{CO_2}$ (greenhouse gases).
- The estimation of the external costs are calculated by multiplying
  - **The emission coefficients:**
    - For the vessels, Technological University of Denmark and the University of Southern Denmark
    - For the road transport (Ntziabchristos and Samaras (2012)): tier 1 and tier 2, for the calculation of SO_2 and Tier1 for NOx, $PM_{2.5}$ and CO_2 (The European Environment Agency)
  - **The unitary costs** (Maibach et al., 2008)of the emitted gases are dependent on the countries and on the kind of zone: metropolitan or urban

First Step: Introduction to a new objective function **F3**

- • **speed of the vessel in knots**
- • **type of cargo unit: TEUs or FEUs**
- • **cargo capacity (*Gp*; ∀*p* ∈ *PP*) measured in units**
- • **age of vessel in years (*Eq*; ∀*q* ∈ Q), with {1, 6, 14} as possible values**
- • **cargo handling systems which are vessel or port cranes**
- • **bow thruster feasibility**
- • **yearly trips (*Ntrips*).**

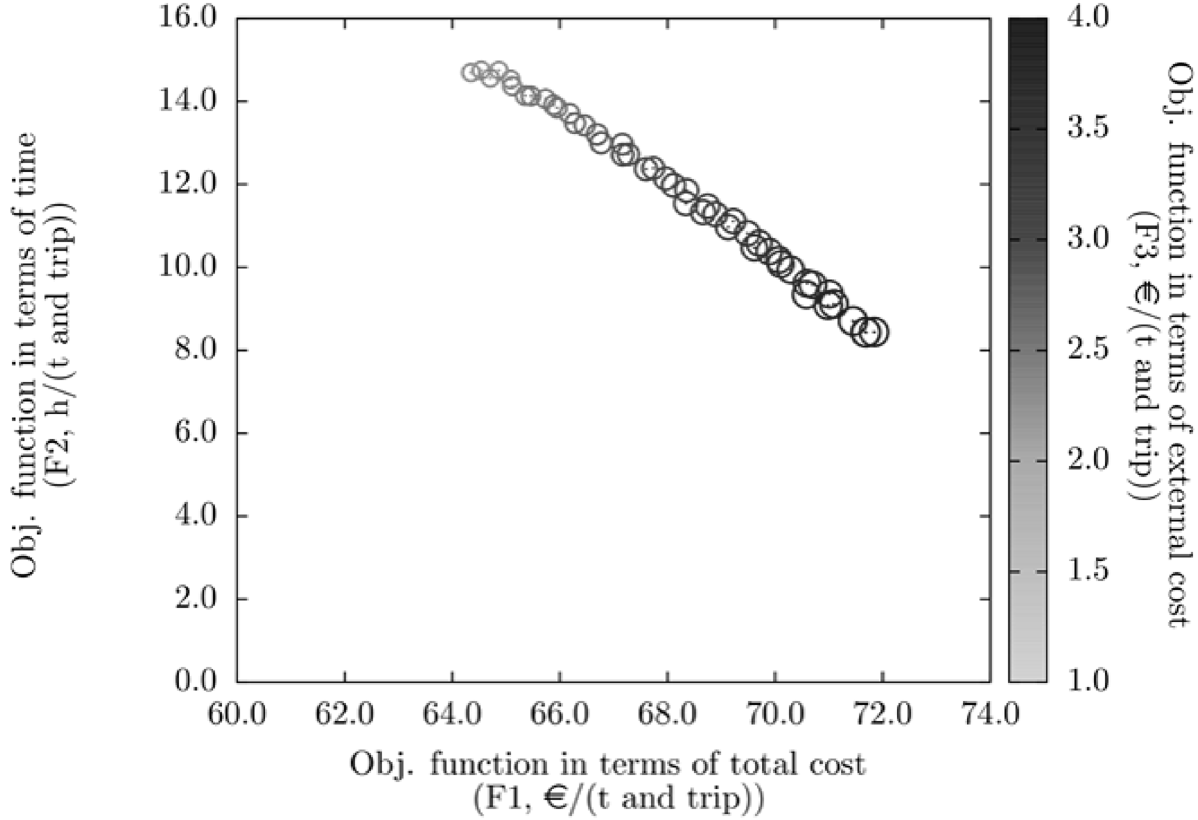
These parameters made up the **chromosomes of the NSGA-II** population.

- During the evolutionary process these genes take values between –1.0 and 1.0, as it is required when using JEAF (Caamano et al., 2010) the **EA framework used in this work**.
- For the evaluation of the possible solutions, each chromosome is decoded to its possible values.
- The NSGA-II algorithm has been applied with the configuration parameters:

Operator	*Parameter*	*Value*
Tournament selection	Pool size	2
SBX-crossover	Probability	5%
Polynomial mutation	Probability	60%
	N	1

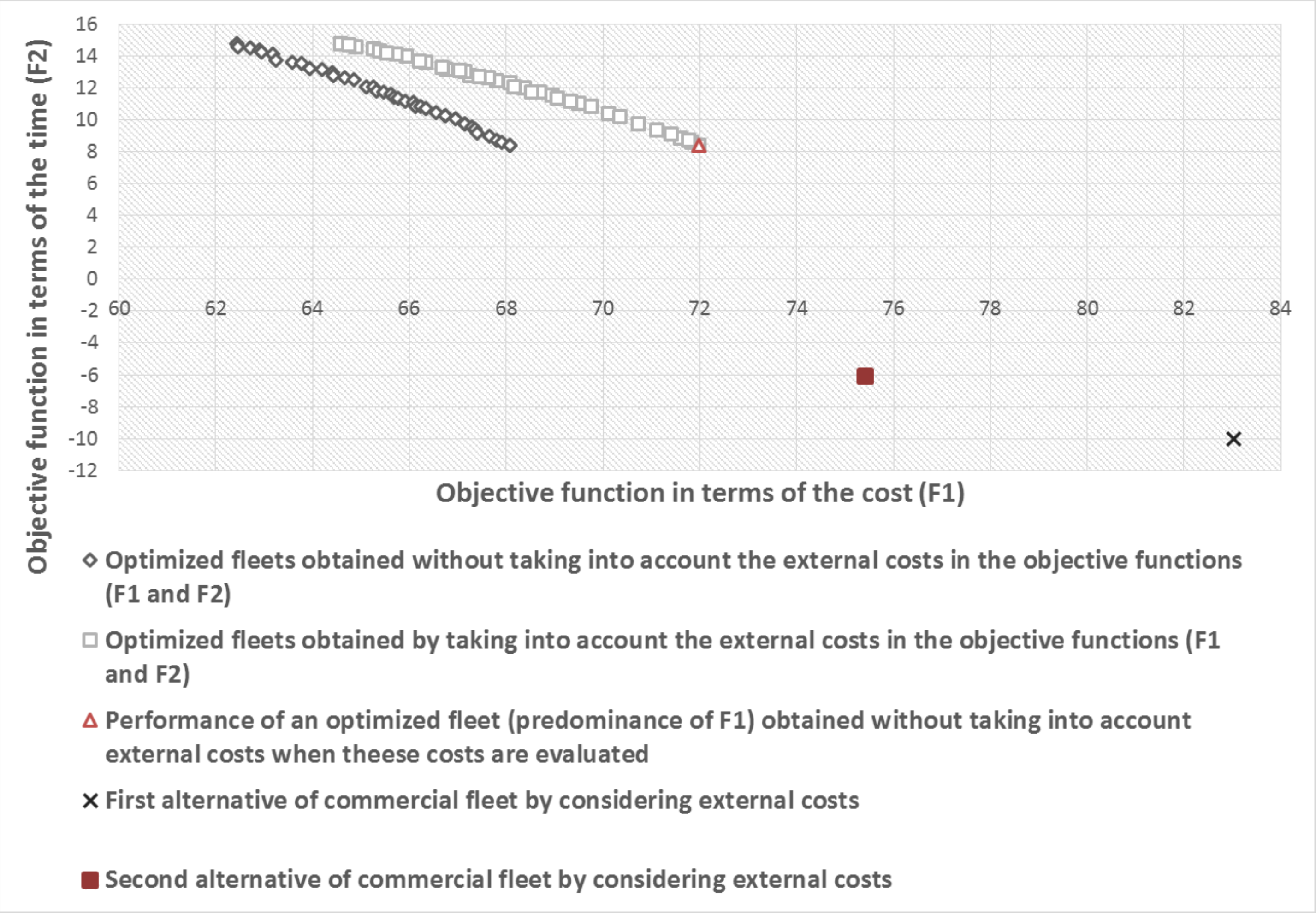
First Step: Introduction to a new objective function **F3**

- The intermodal transport has resulted in being more environmental friendly than the road transport in the framework assumed in this study-case.



First Step: Introduction to a new objective function **F3**

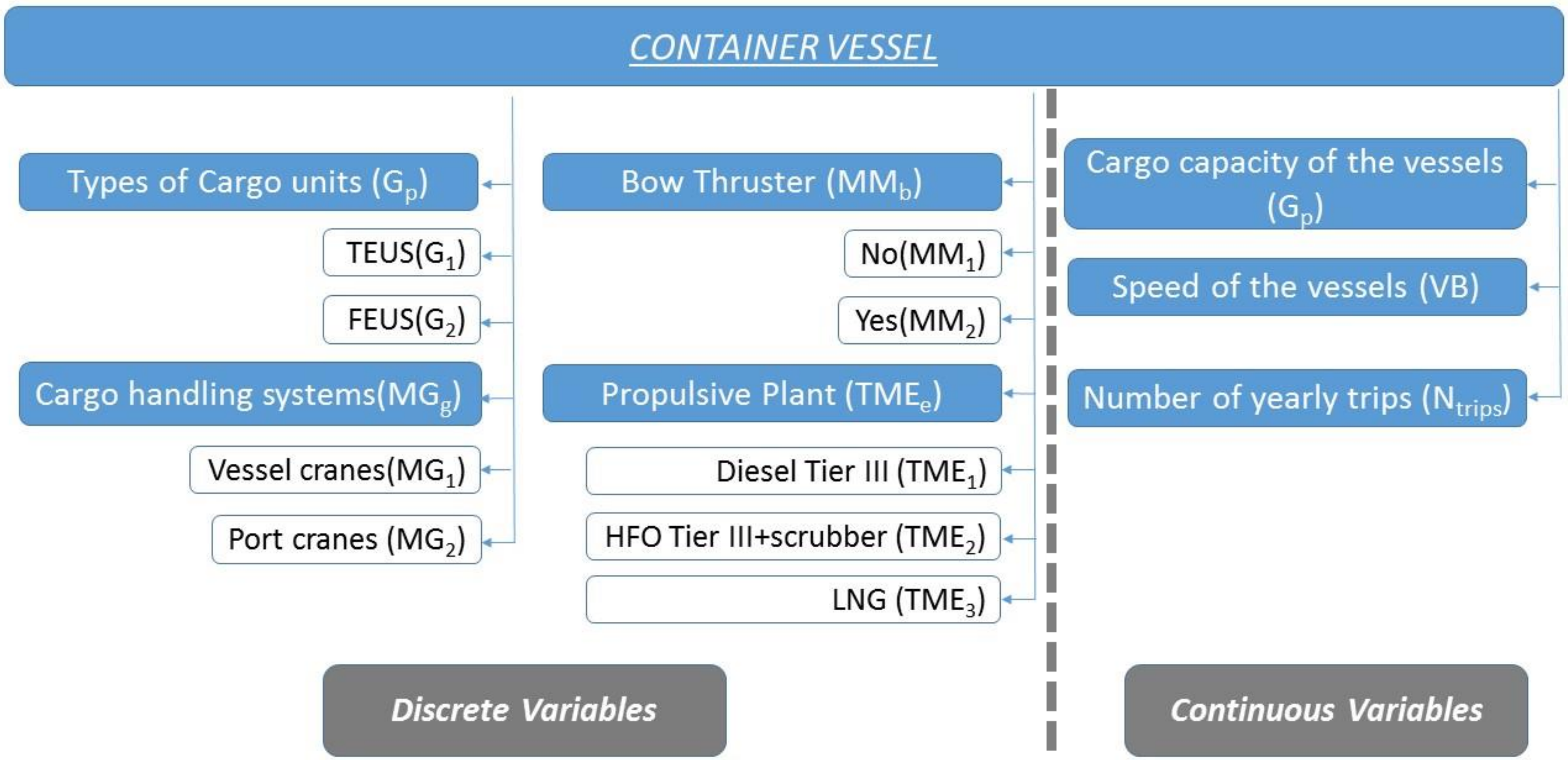
- The **Pareto fronts are not parallel**; the favourable impact of external costs on the competitiveness of the intermodal transport is highly dependent on the solution fleet considered.



Second Step: inclusion of the kind of propulsion plant, its abatement systems and its combustibles

- The environmental regulations have not been as quick or restrictive for maritime transport as for land transport in the EU.
  - **For heavy duty vehicles** from January 2014, Euro VI technology is required in the EU. The Euro VI emission standards involve a 50% reduction of particulate pollutants and 77% reduction of NOx emissions compared to Euro V .
  - **In the maritime context,** Nowadays in Europe only the Baltic Sea, the North Sea, and the English Channel are classified as Sulphur Emission Control Area (SECA)
- The technological development focused on the reduction of pollutant emissions has clearly been slower in the maritime sector
- The technical and operative features of SSS vessels (small and fast ships) along with the modal shift necessary for the door-to-door transport do not favour the sustainability of the intermodal chains

Second Step: the inclusion of the kind of propulsion plant, its abatement systems and its combustibles



Seven independent variables: the age of vessels and type of vessels were ruled out as optimization variables

Second Step: inclusion of the kind of propulsion plant, its abatement systems and its combustibles

- Alternatives of propulsion plants to accomplish with Emission Control Area **(ECA) zones** where SO_2 and NO_x emissions are restricted
  - TMM1:a medium speed four-stroke diesel engine with **MGO** (Tier III).
  - TMM2:a medium-speed four-stroke diesel engine (Tier-III) **with scrubber by operating with HFO**
  - TMM3: a **LNG** propulsion plant
- All engines are compliant with IMO Tier III. This involves the setting up of the **SCR (Selective Catalytic Reduction) systems** except for gas-based engines.

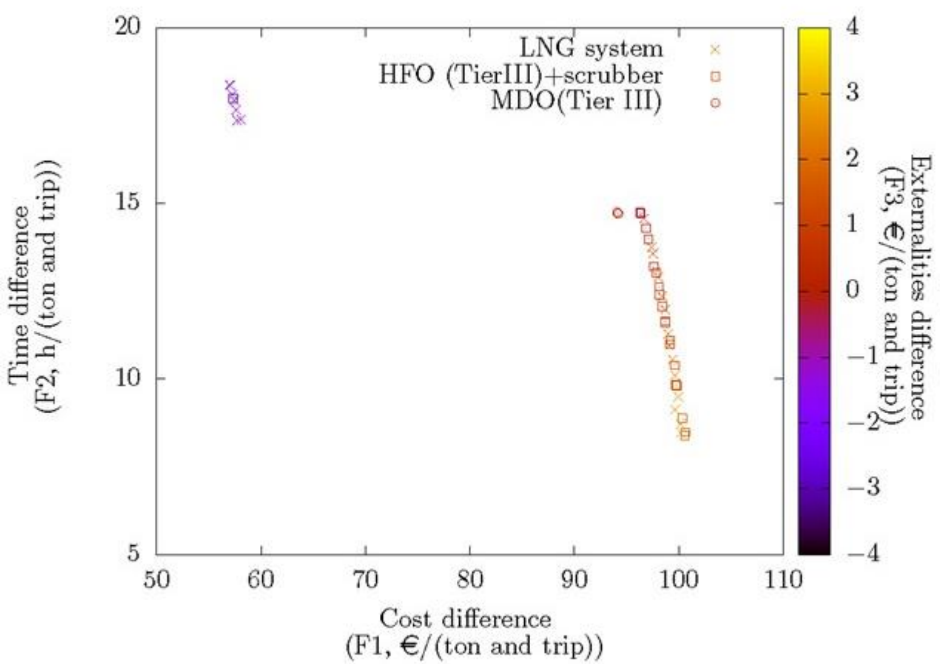
LSMGO (0.1% Sulphur) (*TMM1* alternative)	IFO380 (Max. 3.5%Sulphur bunkers) (*TMM2* alternative)	LNG (Max. 3.5%Sulphur bunkers) (*TMM3* alternative)

Second Step: inclusion of the kind of propulsion plant, its abatement systems and its combustibles

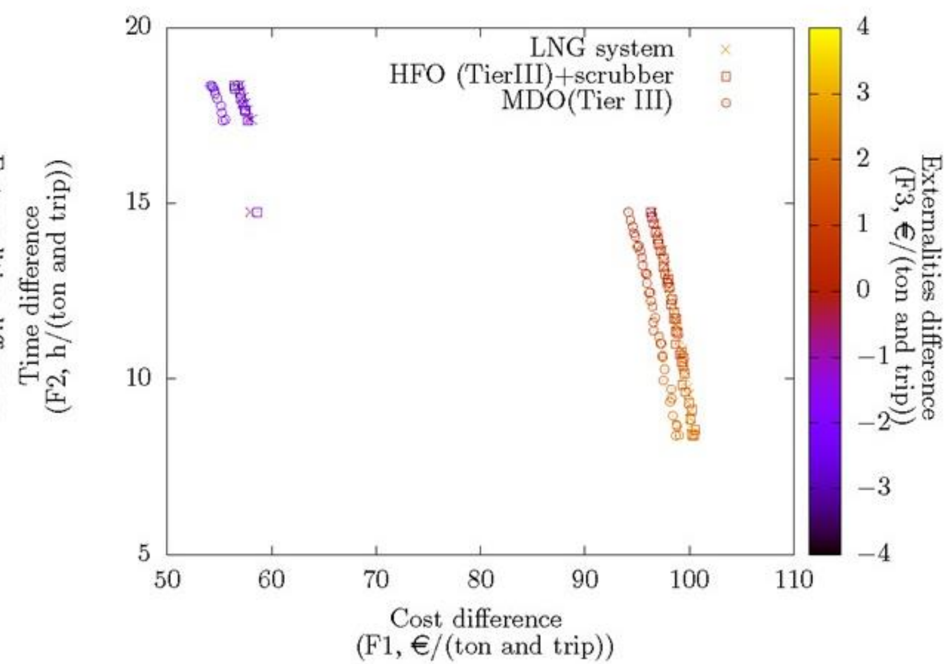
- **Methane slip** is namely the unburnt methane from the combustion of LNG and methane leakage
- Tt is widely accepted that CH_4 is 25 times more harmful than CO_2
- The present model introduces **an environmental assessment of CH_4** owing to the high expected repercussions of this pollutant in the operation of vessels with LNG systems

Second Step: inclusion of the kind of propulsion plant, its abatement systems and its combustibles

Optimization fleet with selection of most suitable propulsion plant



Optimization fleet per kind of propulsion plant



Maritime Route	Vigo-St.Nazaire		
Year	2015	2015	2015
Type of cargo unit	TEUs	TEUs	TEUs
Amount of cargo (G_2)	184 (G_1)	185 (G_1)	184 (G_1)
Vessel speed (Kn)	19.49	19.47	19.49
Age of the vessels	New building	New building	New building
Bow thruster	No (MM_1)	No (MM_1)	No (MM_1)
Cargo handling system	Port cranes (MG_2)	Port cranes (MG_2)	Port cranes (MG_2)
Number of vessels (NB)	3	3	3
Yearly trips (N)	740	740	740
L (m)	77.60	77.37	78.15
B (m)	14.38	14.35	14.46
D to upper deck (m)	7.39	7.38	7.41
GT (Ton)	2417	2402	2456
Type of propeller	Conventional screw (TP_1)	Conventional screw (TP_1)	Conventional screw (TP_1)
Shaft lines	1 (NSL_1)	1 (NSL_1)	1 (NSL_1)
Type of main engine	**Dual engine (LNG) (TMM_3)**	**Tier-III engine+scrubber (HFO) (TMM_2)**	**Tier-III engine (MGO) (TMM_1)**
Main engines	1	1	1
PB (kW))	5316	5280	5421
Objective Functions			
F_1 (€/t per trip)	101.03	100.52	98.97
F_2 (h per trip)	8.48	8.42	8.39
F_3 (€/t per trip)	2.85	1.90	2.15
Costs (€)			
Propulsion plant cost (PMP)(€)	3,667,746[5]	2,435,671	1,318,239
Yearly maintenance (CT_2) costs (€)	79,399	294,918	265,521
Yearly combustible (CT_3) costs(€)	4,641,706	3,960,871	7,578,338
Yearly pollutant costs due to the shipping stage for the fleet (€)			
NO_X	321.252	589.682	602.530
SO_2	0	70.651	129.033
$PM_{2.5}$	18.251	322.236	166.339
CO_2	4.016.963	6.068.819	5.831.969
CH_4	1.159.433	8.760	8.951

Second Step: inclusion of the kind of propulsion plant, its abatement systems and its combustibles

- Evolution of the environmental performance of the intermodality through MOs 2010-2015:
  - **2010:**vessels with Tier-II propulsion plant (MGO propulsion) and Euro I trucks
  - **2015:** different propulsive plants able to meet with ECA regulations for the vessels and Euro VI technology for trucks

Route	*Vigo–St.Nazaire*	
Year	*2010*	*2015*
Type of cargo unit	TEUs	TEUs
Amount of cargo (G_2)	210 (*G_1*)	189 (*G_1*)
Vessel speed (Kn)	19.19	19.81
Age of the vessels	New building	New building
Bow thruster	No (*MM_1*)	No (*MM_1*)
Cargo handling system	Port cranes (*MG_2*)	Port cranes (*MG_2*)
Number of vessels (NB)	3	3
Yearly trips (N)	740	740
L (m)	82.04	79.77
B (m)	15.00	14.68
D to upper deck (m)	7.59	7.48
GT (t)	2743	2489
Type of propeller	Conventional screw	Conventional screw (*TP_1*)
Shaft lines	1	1 (*NSL_1*)
Type of main engine	Tier-II. Diesel engine (MGO) (*TMM_1*)	Dual engine (LNG) (*TMM_3*)
Main engines	1	1
PB (kW))	5942	5573
Objective Functions		
F_1 (€/t per trip)	71.77	101.31
F_2 (h per trip)	8.40	8.44
F_3 (€/t per trip)	3.98	2.85

The **evolution of the sustainability** of the transport systems has been **more favourable for trucking than for the maritime transport.** The value of *F3* remains positive, the results **confirm the negative consequences of the inequality in the environmental normative** of land transportation compared to maritime transport in the EU.

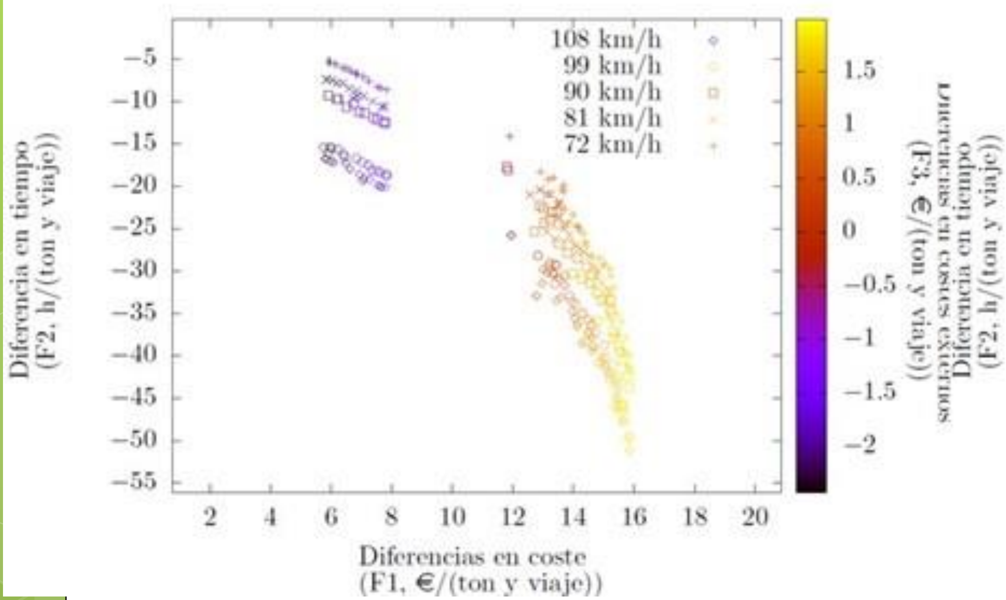
Additional Applications

- The model was adapted to other frameworks and application cases:
  - **Chile: the analysis of the feasibility to articulate MOs between the V Region and the regions of the North and South of the country to articulate intermodal chains. Sensitivity analysis to identify the most influent variables on the success of the intermodality**
  - **North Sea Region: the analysis and selection of the optimal fleet for Rosyth-Zeebrugge route**

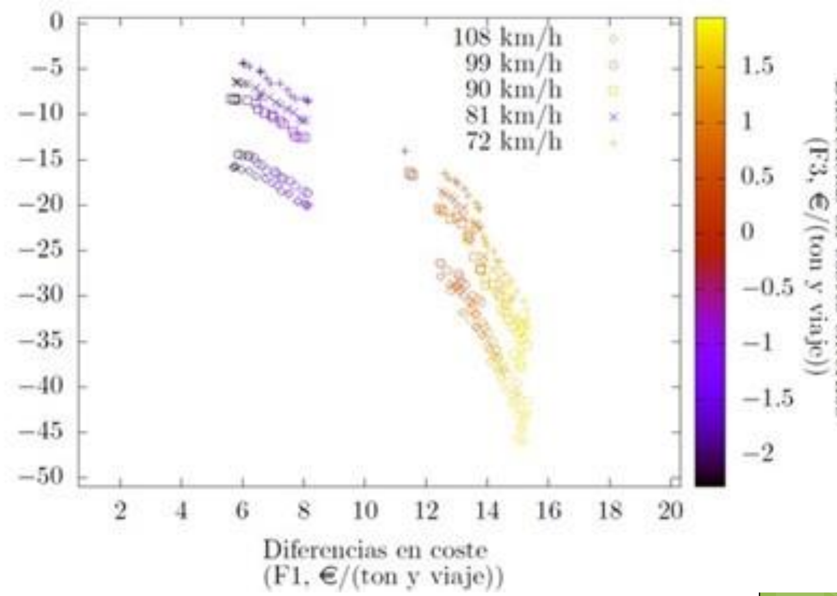
Additional Applications

MOs Norte

S. Antonio-Antofagasta



Valparaiso-Antofagasta



Conclussions

- **The performance** of the mathematical model **has been good** in the applications cases tested by offering **realistic results.**
- Through the resolution of the model with evolutionary algorithms we have been able to offer **useful information** for decision makers about real complex problems about ''door to door'' transport.
- The resolution of this model in its different ways through the time has enabled to obtain **global findings** regarding the intermodality:
  - The **container vessel** is the most interesting kind of vessel for Mos
  - With optimized vessels the intermodality can be **most competitive than trucking in terms of time**
  - Despite the intermodality through SSS is more environmental friendly than the road transport, if the **imbalance** in the normative development continues **the Short Sea Shipping will loos its green label**.
  - The **most suitable propulsion plant** for the vessels operating under MOs is **dual engines of LNG** , despite of the high initial investment required

Thank you for your attention

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