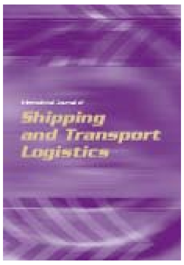
International Journal of Shipping and Transport Logistics



Editor in Chief: Dr. Y.H. Venus Lun
ISSN online: 1756-6525
ISSN print: 1756-6517
6 issues per year
Subscription price

Calls for papers

TR impact factor 2013: 1.34 [76/172 in Management]
[15/29 in Transportation]

IJSTL is an international peer-reviewed journal addressing all methodological aspects in the field of shipping and transport logistics, particularly those that require empirical or mathematical analysis with managerial implications. *IJSTL* is dedicated to publishing original, high-quality and methodologically rigorous research papers that address significant management issues pertinent to shipping/transport logistics. *IJSTL* also publishes informative and critical book reviews of newly published books with scholarly and practical contributions that advance the state-of-the-art of the theory and practice of shipping/transport logistics.

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- Container positioning in liner shipping
- International trade and shipping
- Managing intermodal transport
- Market analysis in sectors of shipping and transport logistics
- Modelling and analysis of problems pertinent to shipping and transport logistics
- Risk analysis in transport logistics and physical distribution infrastructure
- Service quality in shipping and transport logistics
- Strategic alliances and relationship management in shipping and transport distribution
- Strategic management for managing shipping and transport logistics
- Transhipment and the development of hub and spoke in shipping
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- IT and decision support systems for shipping management and physical distribution
- Warehouse and terminal operations and management

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Vol. 6
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Journal Search

Search query

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Exact phrase

International Journal of Shipping and Transport Logistics

Country: United Kingdom

Subject Area: Decision Sciences | Business, Management and Accounting | Social Sciences

Subject Category:

Quartile (Q1 means highest values and Q4 lowest values)

Category	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
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Management of Technology and Innovation													Q2	Q2	Q2
Management Science and Operations Research													Q2	Q2	Q2
Transportation													Q2	Q2	Q2

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H Index: 7

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Charts Data

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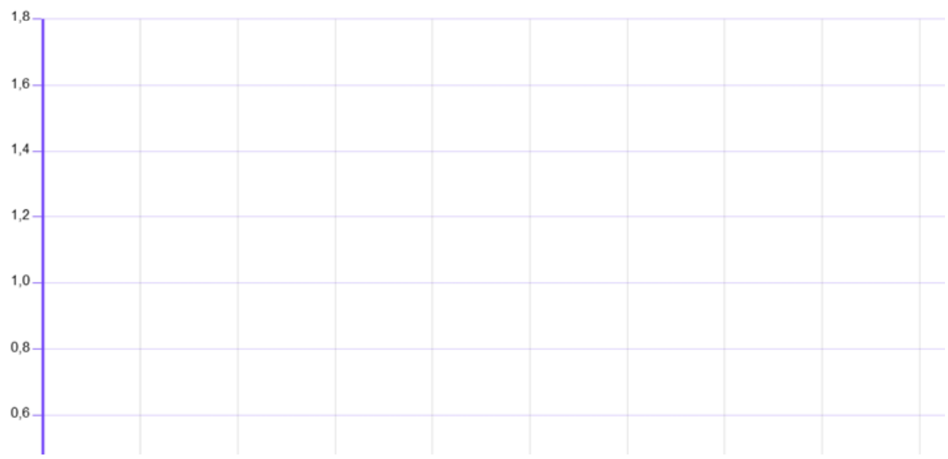

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Subject Category: **Transportation**.
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1	Transportation Research, Series B: Methodological	j	Q1 3,306	70	135	301	4.613	1.356	294	4,36	34,17	
2	Transportation Science	j	Q1 3,139	64	39	103	1.369	334	103	2,93	35,10	
3	Transportation Research, Part A: Policy and Practice	j	Q1 2,433	65	134	276	6.238	930	264	3,07	46,55	
4	Transportation Research, Part E: Logistics and Transportation Review	j	Q1 2,155	52	114	263	3.534	927	255	3,12	31,00	
5	Transportmetrica A: Transport Science	j	Q1 2,150	13	46	62	1.682	123	59	1,86	36,57	
6	Tourism Management	j	Q1 1,961	80	127	438	8.474	1.665	406	3,45	66,72	
7	Journal of Travel Research	j	Q1 1,958	59	59	151	3.974	444	149	2,64	67,36	
8	Transportation Research Part C: Emerging Technologies	j	Q1 1,943	55	227	285	7.294	1.054	256	3,98	32,13	
9	Journal of Transport Geography	j	Q1 1,715	43	162	400	7.439	1.114	378	2,54	45,92	
10	Transport Reviews	j	Q1 1,678	34	39	112	2.373	276	107	2,19	60,85	
11	Transport Policy	j	Q1 1,666	40	138	273	5.439	605	260	2,14	39,41	
12	Transportation	j	Q1 1,645	42	84	177	3.188	346	165	1,89	37,95	
13	International Journal of Sustainable Transportation	j	Q1 1,556	8	17	65	572	93	62	1,35	33,65	
14	International Journal of Physical Distribution and Logistics Management	j	Q1 1,305	34	40	130	2.480	383	127	2,66	62,00	
15	Transportation Research, Part D: Transport and Environment	j	Q1 1,255	44	111	248	1.316	510	244	1,96	11,86	
16	Research in Transportation Economics	j	Q1 1,130	13	106	155	3.498	203	138	1,32	33,00	
17	Economics of Transportation	j	Q2 1,120	3	14	7	403	14	6	2,33	28,79	
18	IWCTS 2012 - 5th ACM SIGSPATIAL International Workshop on Computational Transportation Science	p	1,093	1	0	10	0	2	8	0,25	0,00	
19	International Journal of Tourism Research	j	Q2 1,093	15	93	148	5.512	270	144	1,37	59,27	
20	International Journal of Logistics Management	j	Q2 1,088	8	21	60	1.199	117	59	1,32	57,10	
21	Transportation Research Part F: Traffic Psychology and Behaviour	j	Q2 1,016	43	101	166	4.229	354	165	1,80	41,87	
22	Maritime Policy and	j	Q2 1,009	31	62	121	1.927	235	115	1,87	31,08	

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23	Journal of Transportation Engineering	j	Q2	0,970	42	139	407	3.388	490	398	1,04	24,37
24	European Journal of Transport and Infrastructure Research	j	Q2	0,912	10	18	72	764	99	69	1,22	42,44
25	Maritime Economics and Logistics	j	Q2	0,896	27	22	68	842	102	66	1,46	38,27
26	Journal of Air Transport Management	j	Q2	0,857	34	84	251	2.855	290	234	1,12	33,99
27	Public Transport	j	Q2	0,768	8	18	37	479	38	33	1,17	26,61
28	IET Intelligent Transport Systems	j	Q2	0,760	15	55	128	1.431	245	124	1,67	26,02
29	International Journal of Shipping and Transport Logistics	j	Q2	0,712	7	37	70	1.507	86	70	1,21	40,73
30	Journal of Transportation Safety and Security	j	Q2	0,680	5	21	64	567	51	63	0,56	27,00
31	Sustainable Cities and Society	j	Q2	0,677	7	42	65	1.413	125	63	1,98	33,64
32	Journal of Transport Economics and Policy	j	Q2	0,624	33	29	69	800	62	69	0,84	27,59
33	2010 IEEE Vehicular Networking Conference, VNC 2010	p		0,613	6	0	49	0	63	48	0,00	0,00
34	International Journal of Crashworthiness	j	Q2	0,593	21	61	166	1.635	198	165	1,13	26,80
35	Research in Transportation Business and Management	j	Q2	0,560	3	54	65	2.398	41	57	0,72	44,41
36	International Journal of Transport Economics	j	Q3	0,541	14	18	44	814	33	43	0,66	45,22
37	Transportation Planning and Technology	j	Q3	0,502	21	42	143	1.279	100	139	0,57	30,45
38	European Transport - Trasporti Europei	j	Q3	0,500	4	22	62	897	47	58	0,69	40,77
39	European Transport Research Review	j	Q3	0,480	5	45	67	1.294	44	60	0,65	28,76
40	Zhongguo Gonglu Xuebao/China Journal of Highway and Transport	j	Q3	0,472	16	148	380	2.673	211	380	0,56	18,06
41	World Review of Intermodal Transportation Research	j	Q3	0,460	5	13	23	536	13	23	0,17	41,23
42	Transportation Letters	j	Q3	0,426	7	21	59	775	34	59	0,51	36,90
43	IATSS Research	j	Q3	0,425	4	18	40	481	38	40	0,81	26,72
44	Transportation Journal	j	Q3	0,402	23	26	75	1.005	34	59	0,30	38,65
45	Journal of Public Transportation	j	Q3	0,354	2	29	58	770	28	58	0,48	26,55
46	Jiaotong Yunshu Xitong Gongcheng Yu Xinxi/ Journal of Transportation Systems Engineering and Information Technology	j	Q3	0,329	12	159	574	1.670	218	574	0,34	10,50
47	Mobilization	j	Q3	0,327	15	0	67	0	53	66	0,40	0,00
48	Journal of Transport and Land Use	j	Q3	0,326	3	20	21	741	13	20	0,65	37,05
49	Journal of Transportation Security	j	Q3	0,288	5	27	62	775	39	58	0,59	28,70
50	IEEE Vehicular Networking Conference, VNC	p		0,285	4	42	77	621	80	74	1,08	14,79

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	Title	Type	SJR	H index	Total Docs. (2013)	Total Docs. (3years)	Total Refs.	Total Cites (3years)	Citable Docs. (3years)	Cites / Doc. (2years)	Ref. / Doc.	Country
51	Journal of Productivity Analysis	j	Q1 0,825	48	86	128	3.172	161	122	1,07	36,88	
52	Biomedical Materials	j	Q1 0,765	32	77	270	3.312	609	263	2,36	43,01	
53	Foundations and Trends in Entrepreneurship	j	Q1 0,761	14	5	9	891	16	9	1,20	178,20	
54	Futures	j	Q1 0,758	45	83	356	3.707	470	328	1,27	44,66	
55	Sport Management Review	j	Q1 0,754	20	67	109	2.431	162	107	1,43	36,28	
56	International Journal of Cross Cultural Management	j	Q1 0,734	25	20	59	1.400	73	56	1,00	70,00	
57	European Management Review	j	Q1 0,732	10	17	60	1.231	81	47	1,23	72,41	
58	International Journal of Intercultural Relations	j	Q1 0,724	41	70	221	3.566	328	215	1,43	50,94	
59	American Journal of Evaluation	j	Q1 0,713	30	48	121	1.146	175	113	1,18	23,88	
60	TQM Journal	j	Q1 0,712	35	44	128	1.584	178	127	1,05	36,00	
61	International Journal of Shipping and Transport Logistics	j	Q1 0,712	7	37	70	1.507	86	70	1,21	40,73	
62	International Transactions in Operational Research	j	Q1 0,635	6	57	84	2.116	65	79	0,82	37,12	
63	Journal of Business and Industrial Marketing	j	Q1 0,632	41	57	160	3.561	251	160	1,33	62,47	
64	Journal of International Accounting Research	j	Q1 0,625	5	3	32	216	37	29	1,30	72,00	
65	Accounting in Europe	j	Q1 0,611	7	10	40	597	51	35	1,30	59,70	
66	Tourism Planning and Development	j	Q1 0,589	7	35	88	1.856	78	81	0,59	53,03	
67	Corporate Reputation Review	j	Q1 0,576	8	21	66	1.100	82	63	0,68	52,38	
68	Emerging Markets Review	j	Q1 0,570	22	45	91	2.366	130	90	1,42	52,58	
69	Journal of Consumer Marketing	j	Q1 0,570	48	42	150	2.122	242	149	1,30	50,52	
70	Management and Organizational History	j	Q1 0,565	5	22	65	1.012	31	62	0,56	46,00	
71	Research in Transportation Business and Management	j	Q1 0,560	3	54	65	2.398	41	57	0,72	44,41	

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	1	TRANSPORT RES B-METH	0191-2615	5300	3.894	4.439	0.571	126	9.2	0.01137	1.695
	2	ACCIDENT ANAL PREV	0001-4575	9082	2.571	3.096	0.371	509	7.0	0.01729	0.840
	3	TRANSPORT RES A-POL	0965-8564	3711	2.525	2.855	0.326	129	8.3	0.00801	1.119
	4	TRANSPORT SCI	0041-1655	3038	2.294	2.913	0.541	37	>10.0	0.00494	1.706
	5	J TRANSP GEOGR	0966-6923	2060	2.214	2.768	0.432	148	4.4	0.00567	0.795
	6	TRANSPORT RES E-LOG	1366-5545	2255	2.193	2.943	0.283	99	5.6	0.00718	1.055
	7	TRANSPORTMETRICA	1812-8602	241	2.068	2.022		0	3.7	0.00122	0.813
	8	TRANSPORT POLICY	0967-070X	1555	1.718	2.084	0.179	134	6.4	0.00419	0.750
	9	TRANSPORT RES F-TRAF	1369-8478	1482	1.635	2.349	0.280	100	7.0	0.00329	0.781
	10	TRANSPORT RES D-TR E	1361-9209	1666	1.626	2.040	0.206	107	6.6	0.00439	0.746
	11	TRANSPORTATION	0049-4488	1629	1.617	2.061	0.696	56	8.3	0.00392	0.952
	12	TRANSPORT REV	0144-1647	1016	1.551	2.310	0.892	37	6.7	0.00285	0.927
	13	INT J SUSTAIN TRANSP	1556-8318	159	1.447	1.505	0.333	21	3.6	0.00079	0.510
	13	MARIT POLICY MANAG	0308-8839	884	1.447		0.116	43	9.0	0.00132	
	15	INT J SHIP TRANS LOG	1756-6517	129	1.340	1.337	0.143	35	2.9	0.00042	0.272
	16	J SAFETY RES	0022-4375	2030	1.303	1.940	0.175	63	8.3	0.00401	0.761
	17	TRAFFIC INJ PREV	1538-9588	1106	1.286	1.556	0.296	125	5.1	0.00395	0.560
	18	MOBILITIES-UK	1745-0101	323	1.169	1.348	0.200	35	5.0	0.00145	0.641
	19	MARIT ECON LOGIST	1479-2931	414	1.045		0.100	20	6.9	0.00103	
	20	EUR J TRANSP INFRAST	1567-7133	210	1.023	1.132	0.056	18	5.1	0.00073	0.410

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☐	61	INFORM TECHNOL MANAG	1385-951X	139	0.897	0.942	0.000	23	5.1	0.00043	0.247
☐	62	INNOV-MANAG POLICY P	1447-9338	143	0.439	0.734	0.000	37	4.4	0.00032	0.136
☐	63	INT J ARTS MANAG	1480-8986	96	0.233		0.062	16		0.00005	
☐	64	INT J CONTEMP HOSP M	0959-6119	1037	1.623		0.382	55	6.8	0.00103	
☐	65	INT J FORECASTING	0169-2070	1953	1.390	1.880	0.279	61	9.0	0.00573	1.172
☐	66	INT J HUM RESOUR MAN	0958-5192	3157	0.928	1.580	0.232	207	6.7	0.00644	0.461
☐	67	INT J LOGIST MANAG	0957-4093	788	1.135		0.053	19	8.9	0.00095	
☐	68	INT J LOGIST-RES APP	1367-5567	335	0.469	0.788	0.031	32	7.6	0.00057	0.257
☐	69	INT J MANAG REV	1460-8545	1066	2.673	4.468	0.520	25	6.1	0.00300	1.615
☐	70	INT J MANPOWER	0143-7720	592	0.473	0.818	0.073	55	8.1	0.00112	0.304
☐	71	INT J OPER PROD MAN	0144-3577	3238	1.518	2.472	0.100	60	>10.0	0.00240	0.541
☐	72	INT J PHYS DISTR LOG	0960-0035	1724	1.759	2.322	0.175	40	9.4	0.00196	0.563
☐	73	INT J PROJ MANAG	0263-7863	2879	1.758		0.289	97	7.7	0.00308	
☐	74	INT J SELECT ASSESS	0965-075X	879	0.846	1.042	0.128	39	9.7	0.00179	0.501
☐	75	INT J SHIP TRANS LOG	1756-6517	129	1.340	1.337	0.143	35	2.9	0.00042	0.272
☐	76	INT J STRATEG PROP M	1648-715X	158	1.423	1.025	0.222	27	3.0	0.00030	0.154
☐	77	INT J TECHNOL MANAGE	0267-5730	827	0.492	0.659	0.125	40	8.4	0.00120	0.176
☐	78	INT SMALL BUS J	0266-2426	772	1.397	1.938	0.143	42	7.0	0.00117	0.430
☐	79	INT T OPER RES	0969-6016	566	0.481		0.068	44	9.5	0.00189	
☐	80	INTERFACES	0092-2102	1207	0.443	0.669	0.298	47	>10.0	0.00087	0.286

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THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

SRC
Shipping Research Centre
航運研究中心
The Hong Kong Polytechnic University

30 September 2014

Dear Prof. Alba Martínez López,

Ref: IJSTL-48542

This letter serves as the official acceptance notice that your paper entitled "Definition of Optimal Fleets for Sea Motorways: the Case of France and Spain on the Atlantic Coast" has been critically reviewed by referees with favourable results. Final decision for the revised version of your paper is made. We are pleased to formally accept the paper for publication in the *International Journal of Shipping and Transport Logistics* (*IJSTL*). Your manuscript is scheduled to be published in 2015.

Should you have further inquiries regarding the publication of this paper, please feel free to contact Ms. Barbara Curran, the Journal Manager of Inderscience Publishers at barbara@ielan.com

Yours Sincerely,

Dr Venus Lun

Director of Shipping Research Centre
Department of Logistics and Maritime Studies
The Hong Kong Polytechnic University

Editor-in-Chief
International Journal of Shipping and Transport Logistics

Alba Martínez López

De: Barbara Curran <barbara@ielan.com>
Enviado el: venres, 14 de marzo de 2014 12:13
Para: alba.martinezl@udc.es
CC: 'Lun, Venus [LMS]'
Asunto: FW: publication date IJSTL

Dear Prof.Dr. Alba Martínez López

The paper is scheduled in an issue in 2015. The date and issue number for publication are not yet finalised. You will receive a pdf via email with full citation and page numbers when the issue is sent to press.

The paper can be seen listed as forthcoming at:
http://www.inderscience.com/info/ingeneral/forthcoming.php?jcode=ijstl

Thank you for your patience.

kind regards
Barbara

Barbara Curran
Journal Manager
Inderscience Publishers
www.inderscience.com

From: Submissions [mailto:submissions@journalservice.net]
Sent: 14 March 2014 10:06
To: Barbara Curran
Subject: FW: publication date

Dear Barbara,
Ref: IJSTL-48542, entitled "Definition of optimal fleets for Sea Motorways: the case of France and Spain on the Atlantic coast"

Could you please help?

Best regards,

Joane
submissions@inderscience.com

From: Alba Martínez López [mailto:alba.martinezl@udc.es]
Sent: Thursday, March 13, 2014 6:33 PM
To: 'Submissions'
Subject: RE: publication date

Dear Joane

We have not received any mail from the Dr. Y.H. Venus Lun...could you help us with this issue?

Thank you in adavance

Best regards

Prof.Dr. Alba Martínez López

(PhD. Naval Engineer and Naval Architect)
The Integrated Group for Engineering Research
University of A Coruña
Edificio de Talleres (Campus de Esteiro)
C/ Mendizábal s/n 15403 Ferrol (Spain)
Telf. +34981337400 ext. 3848/3866
http://www.gii.udc.es

De: Submissions [mailto:submissions@journalservice.net]
Enviado el: mércores, 05 de marzo de 2014 10:48
Para: venus.lun@polyu.edu.hk
CC: 'Alba Martínez López'
Asunto: FW: publication date

Dear Editor,

FW for your kind attention.

Best regards,

Joane
submissions@inderscience.com

From: Alba Martínez López [mailto:alba.martinezl@udc.es]
Sent: Tuesday, March 04, 2014 4:38 PM
To: submissions@inderscience.com
Subject: publication date

Dear Dr. Y.H. Venus Lun

Do you have any estimation of the publication date for our work : IJSTL-48542?. The author´s final review was completed on 4th February and we did not hear anything from you since then

Any information about this would be very apreciated.

I take advantage of the opportunity to send you cordial greetings

Sincerely,

Prof.Dr. Alba Martínez López

(PhD. Naval Engineer and Naval Architect)
The Integrated Group for Engineering Research
University of A Coruña

Alba Martínez López

De: Laura Castro Santos <laura.castro.santos@udc.es>
Enviado el: sábado, 01 de febreiro de 2014 9:27
Para: Alba Martínez López
Asunto: RE: Refereeing Decision IJSTL_48542

Bien!!!

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El sábado, 1 de febrero de 2014 a las 03:28, Submissions escribió:

Dear author(s) Pilar Caamano-Sobrino, Alba Martinez-Lopez, Laura Castro-Santos, Blanca Priego-Torres,

Ref: Submission "Definition of optimal fleets for Sea Motorways: the case of France and Spain on the Atlantic cost"

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Submission

Title:	**Definition of optimal fleets for Sea Motorways: the case of France and Spain on the Atlantic coast**
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Paper submitted for the : International Journal of Shipping and Transport Logistics

NOTE TO EDITOR: Dear Dongping Song, First of all, we would to thank you your comments about our paper ´Definition of the optimal fleet for the Sea Motorways: the case of Vigo-St.Nazaire" (Submission code: IJSTL-44130, we really think they have helped to improve the manuscript.Attending these suggestions we re-submit the paper with the implemented comments. Aditionally we have introduced in the paper the last findings regarding this project. For this reason we have decided to change the title of the paper to ´Definition of optimal fleets for Sea Motorways: the case of France and Spain on the Atlantic cost´. We hope you find it interesting. Thank you for helping us to improve our work. Best regards Dra. Alba Martinez-Lopez

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5 Articles

5 Articles

Definition of optimal fleets for Sea Motorways: the case of France and Spain on the Atlantic coast

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Abstract: This work introduces an optimisation model to define the technical and operative features of fleets, which maximises the success opportunities in terms of cost and time for multimodal chains against the road. This model regards the relationships among technical alternatives for fleets, vessels, port facilities, cargo units and their influence on the activity of 'many to many' transport networks through short sea shipping. From the resolution of the model, it is possible to define not only the kind and number of vessels and cargo units, their manoeuvre means, speed and cargo handling systems, but also their naval architecture and engineering. A multiobjective evolutionary algorithm, the NSGA-II, has been applied to resolve this model as applied to multimodal chains between Spain and France through the Atlantic coast. Its application allows to verifying the utility of the model proposed. Finally, the most suitable fleets for the Sea Motorways Vigo-St.Nazaire and Gijón-St.Nazaire have been identified.

Keywords: Sea Motorway; fleet management; non-linear optimisation model; evolutionary algorithms; Spain; France.

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1 Introduction

With the intention of finding alternatives for the traffic congestion problem on European roads, the European Union (EU) boosted its Maritime transport with the concept of Sea Motorways. This concept appeared for the first time in the transport White Paper of 2001 as a group of ports and intermodal services that are used for short distance of maritime transport in a particular zone of the EU. In 2003, in acceptance of the convenience of the Sea Motorways for general European interest, the European Commission reviewed the extension of Trans-European Transport Network (the TEN-T) by including the Sea Motorways in this network.

In this scenario the EU determined that several projects should be finished before 2020.One of these projects was the N21 project which aimed to develop the Sea Motorway concept. The Western European Motorway, which connects Spain and Portugal with the Irish Sea and the North Sea via France, was one of the four motorways selected to be promoted in the first stage of the N21 project.

As a consequence, a collaboration agreement, ‘Declaration of intentions about Sea Motorways’ was signed between France and Spain in October 2005. According to this bilateral agreement, the Sea Motorways projects selected by a Commission (CIG, in July 2006) would receive additional resources (at least 30% of the operating cost for the first three years) but they were required to meet quite demanding conditions (BOE No. 92, 2006) regarding the frequency of the service and the total amount of cargo units transported per year.

In this framework, the first project approved (30 October 2009) was the Vigo-St.Nazaire route (with Acciona-Transmediterranea as the shipping company). Among other advantages, this route was already offering a Ro-Ro linear maritime service to transport the production of the PSA Peugeot Citroen factory located at Vigo (with a yearly production of 380,000 cars). However, despite the favourable situation, the Sea

Motorway never operated. The main reason was that, after losing its agreement with PSA-Citroen in 2010, Acciona-Transmedierranea abandoned the project by arguing that the PSA Citroen production was essential to ensure the feasibility of the Sea Motorway.

In 2010 the Sea Motorway: Gijón-St.Nazaire, operated by GLD Atlantic, was also approved by the Commission. This route has been successfully operating since September 2010 despite the fact that Gijón, in comparison to Vigo, moves less general cargo annually (587,401t versus 2,607,037t in 2009; Port Authority of Gijón, 2009) and fewer containers (175,016 units versus 1,582,047 units in 2009; Port Authority of Vigo, 2009), there exists no car factory in its hinterland and Gijon is not located as far as Vigo from the Pyrenees (see Figure 4).

According to the Port Authorities, the different attitude of shipping companies to the exploitation of both Sea Motorways could be explained by the different number of standard Ro-Ro vessels necessary to cope with the requirements of minimum cargo units and the service frequency demanded by the Bilateral Agreement (the same for both cases).Thus, despite their initial advantages, Vigo-St.Nazaire would have become an unfeasible Sea Motorway due to the additional costs from the operation of a higher number of vessels to cover its longer distance. Thereby, the strategy used by the shipping companies to meet the requirements demanded by Sea Motorways was uniquely based on the modification of the number of standard vessels of the fleet, without considering the utilisation of vessels adapted to the route demands. This practice: the adaptation of the route to the fleet instead the adaptation of the fleet to the route could have led to wrong decisions being made about the feasibility of Sea Motorways

Indeed, the relevance role of the shipping companies in the success of Sea Motorways in particular, and of the multimodal chains in general, is amply recognised by the EU. Nevertheless, numerous authors have highlighted that the recent liberalisation of the maritime sector in the EU (October, 2008) is not sufficient to balance the advantageous situation of the road against the maritime transport. Concretely, the lack of necessary attention to the technical and operative features of maritime transport, the public financing of land transport infrastructure and the costs of externalities of the transport modes has finally led to the EU transferring responsibility for the success of multimodal transport to private initiatives (Baird, 2007; Gesé and Baird, 2013; Romana et al., 2010).

Given this reality, this paper attempts to support the decision-making of the shipping companies when they evaluate the possibility of operating a maritime route as a Sea Motorway integrated in a multimodal chain. Thereby, the main aim of this paper is to provide an optimisation model able to define the most suitable vessels, fleets and their operation for a particular Sea Motorway integrated in a multimodal chain ('many to many' model).

Thus, a general mathematical model will be introduced by considering the objective functions of competitiveness (Lalwani et al., 1991; Mangan et al., 2001): as the maximisation of the difference in terms of time and cost (per tonne transported and per trip) between the unimodal and the multimodal mode. Afterwards, the optimisation will be undertaken by using a multi-objective evolutionary algorithm which enables us to obtain not only the technical and operative parameters of the fleet (kind and number of vessels, cargo capacity, architectural features, speed, frequency, etc.), but also the kind of cargo units and the most suitable cargo handling systems which should be used in order to favour the multimodal chain against the road transport alternative.

Consequently, the results achieved are useful not only for shipping companies or for the Port Authorities, but also for cargo owners who need a transport service for small volumes of cargo with high frequency (for example, SMEs). Due to the problem cited in the case of the Vigo-St.Nazaire Sea Motorway, this route will be taken as a particular case-study for the model application. Finally the model will also be applied to Gijon-St.Nazaire, this will allow the analysis of the affirmations provided by the Port Authorities and the comparison of the performance of this route against the Vigo-St.Nazaire alternative.

2 Literature review

The analyses of the competitiveness of multimodal chains through short sea shipping (SSS) versus the road haulage are numerous in the EU context (Martínez and Olivella, 2005; Paixao and Marlow, 2002; WEST-MOS Project, 2005–2008). Notwithstanding these assessments were attended from very diverse points of view, one of the reached conclusions was amply accepted by all of them: the weakest attribute of the multimodal chain is the time invested in the transport. This affirmation was also concluded by modal choice studies (Feo et al., 2010; Garcia-Menendez and Feo-Valero., 2009), which also determined, the relative importance of time against cost for the multimodal transport as function of the features of the cargo owner (Nellthorp et al., 2001) and the moment of the study (Bergkvist, 2001; Mangan et al., 2001). This reality motived, on the one hand, works which took the cost of the different possibilities of the transport modes as the principal evaluation criterion (Morales-Fusco et al., 2012; Ng, 2009; Perez-Mesa et al., 2010; Sambracos and Maniati, 2012; among others), these were especially significant. On the other hand, many studies analysed those maritime routes which could operate in high speed craft (HSC) conditions (Castells i Sanabra, 2009; Engineering and Physical Sciences Research Council (EPSRC) and UK Department for Transport DfT, 2002–2003; SPIN-HSV Project, 2003–2005) with the intention of assessing if this kind of SSS service would reduce the time invested in multimodal chains. However, the HSC were finally ruled out by most of them due to their high operative costs.

Despite the wide diversity of these studies, two assumptions have been commonly accepted; firstly, the feasibility of multimodal transport is mostly based on one kind of vessel: roll-on roll-off traffic conditions for the maritime leg (Ro-Ro and Ro-Pax vessels). Secondly, the technical and operative features of the vessels, their number (the fleet) and the service conditions, which are finally provided by a shipping company, are considered as fixed initial parameters. As a consequence, these analyses often conclude distance thresholds or particular routes (such as; Bendall and Brooks, 2011; EMMA Study, 1996–1998; Martínez and Olivella, 2005; WEST-MOS Project, 2005–2008), which ensure the success of intermodal transport against road haulage by adapting the route definition to a borne SSS service.

In this context, it is argued that roll-on roll-off vessels were traditionally identified as the most suitable vessels for intermodal transport through SSS (Bernetti et al., 2002; Paixao and Marlow, 2002; WEST-MOS Project, 2005–2008; Woxenius, 2010). Nevertheless, this argument is not convincing for two reasons: the mayority of the studies which support this affirmation are based on qualitative approaches and research, and studies which quantitatively compared the effectiveness of the two possible vessels for SSS (Ro-Ros and container vessels), are very scarce and focused on specific aspects of the transport (Mbiydzenyuy et al., 2010). Moreover, it is commonly accepted that the relative competitiveness of multimodal transport against the road is determined by a combination of the operative and technical features of transport means, customer requirements and geographic characteristics (Baird, 2007; Gesé and Baird, 2013) and this combination determines the modal choice (Feo et al., 2010; Garcia-Menendez and Feo-Valero, 2009). This circumstance leads to competitiveness assessments, which take as fixed inputs the conditions of the SSS service, and the transfer of responsibility to the shipping companies (private initiative); consequently their results accept an important uncertainty level in this regard.

In parallel, studies on ship sizing and on the adaptation of the transport service to the requirements of a particular maritime route were seldom addressed to SSS (Christiansen et al., 2004). Regarding the first group, these studies explored the optimal vessel size with the intention of supporting the shipping companies by taking advantage of the effects of economies of scale (such as Culliane and Khanna, 1998, 2000; Pope and Talley, 1988), especially, on the container traffic for long distances. Notwithstanding their relevant contributions, these studies rarely consider the benefits of the shippers as an objective.

The other group, which contains research on fleet management and shipping planning by adapting the service conditions to the route demand, has reached significant results. Indeed, during the last few years, the routing, scheduling and stowage problems in container traffic (Ambrosino et al., 2004; Martins et al., 2009; Moura and Oliveira, 2009; Triunfante et al., 2010) were amply attended through the application of evolutionary algorithms (EA).

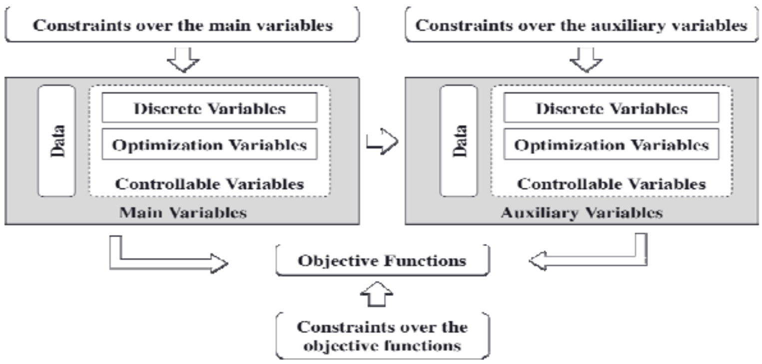
Nevertheless, despite the wide possibilities of analysis offered by these algorithms, the combined problem: simultaneous optimisation of fleets and of their operation was not treated as frequently as expected. The majority of research, which has addressed this combined problem, considers, once again, the containership traffic based on hub and spoke networks (Bendall and Stent, 2001; Hsu and Hsieh, 2007) or liner routes (Cho and Perakis, 1996). These works conclude the optimal frequency, vessels size and route considering the costs related to the maritime shipping. Additionally, those that apply a multi-objective algorithm (Hsu and Hsieh, 2007), offer a significant advantage: a high flexibility, in terms of Pareto fronts, when making global decisions. Despite the fact that some studies treat this combined problem by considering seaborne as a transport leg also exist, they were focused on the resolution of very particular transport problems; the water transport between two countries (Fagerholt and Rygh, 2002) or the shipping of dry bulk minerals from extraction origin to customer sites (Mehrez et al., 1995), instead of the global problem of the relative competitiveness of multimodal chains against the road.

Thus, from a theory standpoint, this work addresses the relative competitiveness problem for multimodal chains through SSS against the road, but also considers the combined problem of the adaptation of the maritime fleet (Ro-Ro and container vessels) and its operation for the requirements of the 'door to door' transport. Thereby, using this approach, this work tries to fill the knowledge gaps identified in the literature review.

3 Methodology

The methodology followed in this work is divided into two phases .The first is devoted to the definition of the mathematical model used to simulate fleets and their operations; this mathematical model defines all variables and the relationships between them that are necessary to define the fleet and its activity in comparison with unimodal transport. The second phase of the methodology is dedicated to the optimisation of the fleets.

Figure 1 Integration of variables objective functions, constraints in the optimisation model



3.1 Mathematical model definition

From a mathematical point of view, the model is made up of three different elements: the variables, the objective functions and the constraints (see Figure 1). At the same time, the variables can be divided in three types according to their roles in the optimisation: the cases (discrete variables), the optimisation variables (continuous) and the data (no controllable inputs imposed by the specific scenario). Additionally, two kinds of variables will be handled in the model: the auxiliary ones (related to naval architecture and naval engineering) and the main variables (related directly with the objective functions and auxiliary variables). The calculation of the first ones is necessary, along with the definition of the second ones, for the calculation of the objective functions (see Figure 1).

It is interesting to bear in mind that, whereas the second classification of the variables is independent on the analysed scenario, the role of the 'controllable' or 'no-controllable' (data) variable will be imposed by each case-study. The variables and the relationships among them allow simulation of the different scenarios, which integrate the alternatives of routes (with their ports), fleets, and the cargo units. In the following sub-sections the variables, which characterise these components, are outlined.

3.1.1 Fleets

This part of the model is focused on the vessel design from a technical point of view but also calculates its impact on the time and cost of the multimodal chain. The model considers the two compatible kinds of vessels for SSS ($Q = \{1, \ldots q\}$), Ro-Ro and container vessels. The general arrangement considered for the generation of Ro-Ro vessels is those of 'Clipper Point' (Royal Institution of Naval Architects, 2008) with three cargo decks. For the container vessels the general arrangement of the 'Sea Arctica' Royal Institution of Naval Architects, 1994) has been taken as reference. For the calculation of the technical features of vessels, the expressions published by different authors have been considered (Lamb, 2004; Rawson and Tupper, 2001; Watson, 2002; among others). Thus, the architecture of the vessel is defined through, among other values, the length (L), breadth (B), depth to the upper deck (D), draught (T), freeboard (FB), gross tonnage (GT), buoyancy volume (∇), deadweight (TPM), speed (VB), propulsion power (PB), (and through other features like the installation of bow thrusters ($BB = \{1, \ldots, b\}$). However, the expected high speed necessary for the vessels to offer a competitive multimodal transport (Engineering and Physical Sciences Research Council (EPSRC) and UK Department for Transport DfT, 2002–2003; SPIN-HSV Project, 2003–2005) suggests a higher required space for the machine rooms and therefore a reduction of the available cargo space in the vessels. For this reason, the model introduces mechanisms (based on the available cargo volume and on the deadweight), which calculate the real maximum cargo capacity of the vessels (G_3), once the arrangement of the machine room has been defined. This is determined by the kind of main engines ($TMP = \{1, \ldots, m\}$) and their number ($NMP = \{1, \ldots, a\}$), the kind of propeller ($TP = \{1, \ldots, h\}$) and the number of shaft lines ($NN = \{1, \ldots, n\}$).

The competitiveness of the multimodal chain in terms of the cost is closely dependent on the capital cost (Grosso et al., 2008; Sauri, 2006) and therefore, on the building cost of the vessel (CC), which depends on its technical features, on its dimensions and the operative characteristics of the vessel, also depending, on the age of the vessel ($EE = \{1, \ldots, e\}$).

Other handled variables (data) for the definition of the fleet are the following:

R_1 percentage of the depreciation of the vessel value

R_4 percentage of the building cost with mortgage

R_2 interest rate of the mortgage

A_1 years of the mortgage

A_2 years of the amortisation

C_3^a average cost of an officer in the crew per year (€)

C_3^b average cost of a sailor per year (€)

C_3^c cost IFO 380 (€/l)

DT_2 diesel density (gr/l)

DT_1 engine consumption (gr/HP.h)

NTR number of persons in the crew

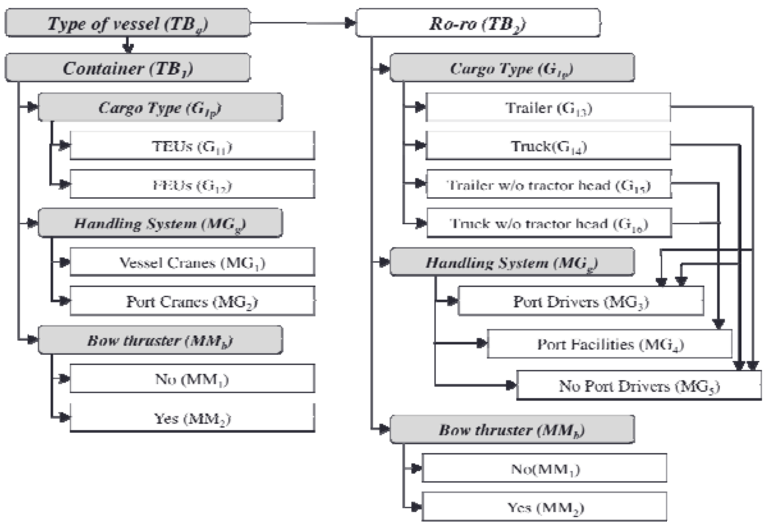
NB number of vessels of the fleet.

Finally with the aim of validating the fleet design model, this has been applied to real ships (Ro-Ro and containers) with dimensions between 85 and 200 m of length between perpendiculars, and the results obtained were very close to the reality.

3.1.2 Cargo

In order to characterise adequately the multimodal chain it is necessary to observe all the compatible cargo units ($PP = \{1, \ldots, p\}$) along with their weight (P_p) for each kind of vessel: TEUS, FEUS, trailers and trucks with and without tractor head (see Figure 2).

Figure 2 The discrete decision variables

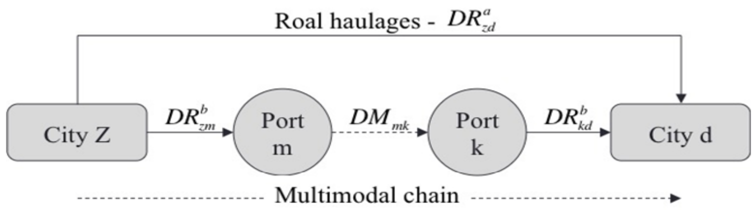


The selection of a particular cargo unit not only defines the cargo capacity of the vessel in units (G_2) but it also determines the possible cargo handling systems used ($G = \{1, \dots g\}$). The features of the cargo handling systems, like the number of operative cranes per vessel (U_g) or the speed of the cranes ($V_{2,g}$), are essential to know the loading/unloading time and therefore the competitiveness in terms of the time of multimodal chains. In this case, we have assumed semi-direct routes inside the port for the unaccompanied cargo units, for the rest of cargo units we have assumed direct-routes under ideal conditions (low transit times inside the port).

3.1.3 Routes and ports

Due to the fact that 'many to many' model is highly adaptable to most real 'door to door' haulages (Daganzo, 2005), this model has been considered for the generation of the routes (see Figure 3). Therefore, the ports of origin ($M = \{1, \dots m\}$) and destination ($K = \{1, \dots, k\}$), the land origins ($Z = \{1, \dots, z\}$) and destinations of the multimodal chain ($DD = \{1, \dots, d\}$) with their probability of being selected as initial origin (X_z) and final destination (X_d) must be included in the model (see Figure 3). Once the routes are defined, they are characterised by using the maritime distance (DM) and the road distances between extreme points and ports (DR^b_{zm}, DR^b_{kd}) and the road haulage distance (DR^a_{zd}). Additionally, the price (€/Km) of the transportation by road $C_{4,p}$ (Observatory of Road Freight Transport Costs, 2010), which is related to the type of cargo, and the maximum speed of the trucks (V_3 in Km/h), is used to estimate the cost of the unimodal mode and the road stretch of the multimodal mode.

Figure 3 'many to many' model for the routes generation



Finally, to correctly simulate the activity of the multimodal chain, it is necessary to characterise the port operations in terms of time and cost. Obviously, this activity is specific for each port, however, in most of the European ports the following variables can be considered for their definition:

$R_{5,q}$ Percentage of dockage due required by the port to stimulate SSS traffic. This depends on the number of trips and the kind of vessel.

TIE Loading/unloading time (h).

$R_{6,q}$ Percentage of cargo due required by the port to stimulate SSS traffic.

$C^{c}_{2,p}$ Cargo dues in the port, which depend on the type of cargo unit.

C^{c} Pilotage dues.

C^{c}_{1} Towing dues.

C^{c}_{2} Mooring dues.

$C^{c4}_{2,p}$ Loading/unloading dues (€/unit).

Tl_{1} Average waiting time for a pilot.

Tl_{2} Average waiting time for the towing service.

Considering all these aspects and the features of vessels and cargo units the model will resolve finally the number of yearly trips for the fleet (N).

Notwithstanding the numerous variables handled in the model (150 without taking into account the data) only eight of them have been identified as no dependent (main variables). The main variables are the ones in charge of defining the activity requirements of the vessels; these are the necessary parameters for the conceptual design of the vessels in the early step of the project (Lamb, 2004; Rawson and Tupper, 2001):

- Discrete variables:
  - a type of vessel ($Q = \{1, \ldots, q\}$)
  - b age of the vessel, in years ($EE = \{1, \ldots, e\}$)
  - c type of cargo unit (PP = {1, …, p})
  - d cargo handling system (G = {1, … g})
  - e bow thruster (BB = {1, …, b})
- Optimisation variables:
  - a Cargo capacity (G2)
  - b Speed of the vessel (*VB*)
  - c Number of vessels in the fleet (*NB*)

The mathematical model has been formulated by taking into account that the main objective of this work is to find the best fleet option, which articulates the most competitive multimodal chains against the road. Thereby, the optimisation objectives aim to maximise the difference in cost and time of the road transport regarding the multimodal chains, from one origin to one destination, considering all the possible origins (Z) and destinations (DD) and the probability of load distribution among them (X_z and X_d). The cost and time formulations have to integrate the information provided by consignee companies and the Port Authorities, as well as the European normative and national rules. Indeed, many of these expressions are highly sensitive to the selected ports and routes. However, the variables implied in their calculation are mostly standard. For this reason although these expressions are not shown with detail, their dependences are explained in this text. On the other hand, the general application expressions, which have been evaluated and fitted by comparison with real values (provided by ship owners, maritime companies and shipyards), are detailed in the following paragraphs.

3.1.4 Maximisation of the difference in cost

The cost of the unimodal (CU) and multimodal transport (CMU) are measured per tonne and per trip considering the probabilities of land destinations (X_z and X_d). The multimodal cost integrates the cost of the road stretches: door to port ($CMU_{1,1}$) and port to door ($CMU_{1,2}$) and the maritime stretch (CMU_2). This last one takes into account all the necessary costs (CT_c) for the calculation of the minimum required freight (to achieve the even point). The costs considered are the capital costs, fixed direct costs and variable costs (Hunt and Butman, 1995; Perez-Mesa et al., 2010; Sauri and Spunch, 2009).

$$F_2 = \max(CU - CMU) \tag{1}$$

$$CU = \left(\sum_{z=1}^{z} \sum_{d=1}^{d} \left(X_z \times X_d \times DR_{zd}^{a} \right) \right) \times \frac{C_{4,p}}{P_p} \qquad \forall p \in PP \wedge \forall z \in Z \tag{2}$$

$$CMU = CMU_{1,1} + CMU_{1,2} + CMU_2 \tag{3}$$

$$CMU_{1,1} = \left(\sum_{z=1}^{z} \left(X_z \times DR_{zm}^{b} \right) \right) \times \frac{C_{4,p}}{P_p} \qquad \forall p \in PP \wedge \forall m \in M \wedge \forall z \in Z \tag{4}$$

$$CMU_{1,2} = \left(\sum_{d=1}^{d} \left(X_d \times DR_{kd}^{b} \right) \right) \times \frac{C_{4,p}}{P_p} \qquad \forall p \in PP \wedge \forall k \in K \wedge \forall d \in DD \tag{5}$$

$$CMU_2 = \left(\sum_{c=1}^{12} CT_c \right) \times \frac{1}{G_3 \times P_p \times N'} \qquad \forall p \in PP \tag{6}$$

Attending to the classical countable criterion, the capital costs have been calculated as the addition of the amortisation cost (CT_1) and the interest cost (CT_2) by considering a straight-line amortisation system for the first one and an arithmetical capital amortisation for the mortgage (Watson, 2002; Stopford, 2009).

$$CT_1 = CC \times \frac{100\% - R_1}{A_2} \times NB \tag{7}$$

$$CT_2 = \left[\left(R_4 \times CC \right) - \left(E_e - 1 \right) \times \left(CC \times R_4 \right) / A_1 \right] \times R_2 \times NB \qquad \forall e \in EE \tag{8}$$

The fixed direct costs are the insurance cost (CT_3), the maintenance cost (CT_4) and the personal cost (CT_5). The first two vary along the lifecycle of the vessel (i.e., depending on the age, *EE*), but while the insurance cost remains practically constant (the depreciation of the vessel worth is balanced with the increase of the damage probability) the maintenance cost, which includes overhauls and repairs, increases. The vessel insurance (CT_3) is mainly integrated by the hull and machinery insurance (H&M) and the protection and indemnity insurance (P&I). Notwithstanding the fact that it is highly dependent on the ship-owner history (accident risk), routes and on the insurance company, in general terms this cost is calculated considering the actual worth and age of the vessels (CT_1, E_e) and their deadweight (*TPM*). The maintenance cost (CT_4) is commonly associated to the vessel construction cost (*CC*) and the age (E_e) because it suggests its technological level and its cost increases with the time (Hunt and Butman, 1995; Stopford, 2009). Finally the personal cost (CT_5) (Sauri and Spunch, 2009; Wijnolst and Wergeland, 2009) takes into account the crew number (*NTR*), the yearly salary costs, for officers (C_3^a) and ratings (C_3^b) by assuming a rotation index for the crew of 0.33 (Sauri and Spunch, 2009; Wijnolst and Wergeland, 2009).

$$CT_3 = \frac{80}{100} \times CC \times \left(1 - \frac{(100\% - R_1)}{A_2} \times E_e \right) \times NB \times \alpha \qquad \forall e \in EE \tag{9}$$

$$\alpha = f(TPM, Ee) \qquad \forall e \in EE \tag{10}$$

$$CT_5 = \begin{cases} \left(\frac{53}{100} \times C_3^a + \frac{47}{100} \times C_3^b \right) \times NB \times NTR & \text{if } TB_q = TB_1 \\ \left(\frac{44}{100} \times C_3^a + \frac{56}{100} \times C_3^b \right) \times NB \times NTR & \text{if } TB_q = TB_2 \end{cases} \tag{11}$$

The variable costs are fuel costs (CT_6) dockage dues (CT_7) cargo dues in port (CT_8), pilotage cost (CT_9), towing cost (CT_{10}), mooring cost (CT_{11}) and loading/unloading costs (CT_{12}). Regarding fuel costs (CT_6), these are very dependent on the time of the trip (TVB_1), and on the arrangement of engine rooms (Baird, 1999; Lamb, 2004) for a determined propulsion power (*PB*): kind and number of engines (*TMP*, *NMP*), number of shaft lines and kind of propellers (*NN*, *TP*); this finally determines the fuel consumption (DT_1).

$$CT_6 = PB \times \frac{DT_1}{DT_2} \times C_3^c \times TVB_1 \times N \tag{12}$$

Port dues (CT_7–CT_{11}) must be calculated considering the information provided by Port Authorities and the Port Regulation of the different countries implied in the route. Despite of the fact that every port has their own tariffs scheme, the dockage, pilotage, towing and mooring costs are often dependent on the number of trips per year (*N*) and on the gross tonnage (*GT*), whereas the cargo dues and loading costs are mainly dependent on the number of cargo units (G_3). In addition to this, the compulsory use of towing services (CT_{10}) is usually conditioned by the manoeuvring means (MM_b) and length (*L*) of vessels. Additionally, the loading costs (CT_{12}) consider the cargo handling system selected (MG_g).

$$CT_7 = f\left(TIE, N, GT, R_{5,q}\right) \qquad \forall q \in Q \; (\textit{see Figure } 2) \tag{13}$$

$$CT_8 = f\left(N, G_3, C_{2,p}^c, R_{6,q}\right) \qquad \forall q \in Q \wedge \forall p \in PP \tag{14}$$

$$CT_9 = f\left(C^c, N, GT\right) \tag{15}$$

$$CT_{10} = f\left(C_1^c, N, GT, MM_b, L\right) \qquad \forall b \in BB \tag{16}$$

$$CT_{11} = f\left(N, GT, C_2^c\right) \tag{17}$$

$$CT_{12} = f\left(N, G_3, C_{2,p}^{c4}, MG_g\right) \qquad \forall p \in PP \wedge \forall g \in G \tag{18}$$

3.1.5 Maximisation of the difference in time

The duration of the unimodal transport per trip (*TVU*) has been estimated in hours per trip, considering the European Normative on the maximum speed for trucks (European Directives 92/24/EC, 92/6/EC) and minimum breaks for the resting of the drivers (Regulation 561/2006 of European Parliament). The duration of the multimodal transport (*TVM*) per trip (measured in hours) considers the maritime and land stretches. Thus, while expressions for the time invested in the road stretches (TVC_1, TVC_2) are the same as the unimodal transport expression but with different road distances (see Figure 3), the time invested in the maritime stretch (*TVB*) is the addition of the duration of the trip by sea (TVB_1), [dependent on the vessel speed (*VB*) and the maritime distance (*DM*)], the loading/unloading time (TVB_2), and the berthing time in port (TVB_3).

$$F_2 = \max(TVU - TVM) \tag{19}$$

$$TVU = \sum_{z=1}^{z}\sum_{d=1}^{d}\left(X_z \times X_d \times \left[\left\lfloor \frac{\left\lfloor \frac{DR_{zd}^{a}}{9\times V_3} \right\rfloor \times 0.75 + \frac{DR_{zd}^{a}}{V_3}}{9} \right\rfloor \times 24 + \left\lfloor \frac{\left\lfloor \frac{DR_{zd}^{a}}{9\times V_3} \right\rfloor \times 0.75 + \frac{DR_{zd}^{a}}{V_3}}{9} \right\rfloor - \left\lfloor \frac{\left\lfloor \frac{DR_{zd}^{a}}{9\times V_3} \right\rfloor \times 0.75 + \frac{DR_{zd}^{a}}{V_3}}{9} \right\rfloor \times 9 \right] \right) \tag{20}$$

$$TVM = TVC_1 + TVC_2 + TVB \tag{21}$$

$$TVC_1 = \sum_{z=1}^{z}\left(X_z \times \left[\left\lfloor \frac{\left\lfloor \frac{DR_{zm}^{b}}{9\times V_3} \right\rfloor \times 0.75 + \frac{DR_{zm}^{b}}{V_3}}{9} \right\rfloor \times 24 + \left\lfloor \frac{\left\lfloor \frac{DR_{zm}^{b}}{9\times V_3} \right\rfloor \times 0.75 + \frac{DR_{zm}^{b}}{V_3}}{9} \right\rfloor - \left\lfloor \frac{\left\lfloor \frac{DR_{zm}^{b}}{9\times V_3} \right\rfloor \times 0.75 + \frac{DR_{zm}^{b}}{V_3}}{9} \right\rfloor \times 9 \right] \right) \tag{22}$$

$$TVC_2 = \sum_{d=1}^{d}\left(X_d \times \left[\left\lfloor \frac{\left\lfloor \frac{DR_{kd}^{b}}{9\times V_3} \right\rfloor \times 0.75 + \frac{DR_{kd}^{b}}{V_3}}{9} \right\rfloor \times 24 + \left\lfloor \frac{\left\lfloor \frac{DR_{kd}^{b}}{9\times V_3} \right\rfloor \times 0.75 + \frac{DR_{kd}^{b}}{V_3}}{9} \right\rfloor - \left\lfloor \frac{\left\lfloor \frac{DR_{kd}^{b}}{9\times V_3} \right\rfloor \times 0.75 + \frac{DR_{kd}^{b}}{V_3}}{9} \right\rfloor \times 9 \right] \right) \tag{23}$$

The expression of TVB_2 compiles the information provided by Stowage Societies of the ports and consignee companies which operate in the selected ports, while TVB_3 results are highly dependent on the mandatory use of pilot and towing services demanded by the Port Authorities.

$$TVB = \sum_{t=1}^{3} TVB_t \tag{24}$$

$$TVB_1 = DM/(VB \times 1.85) \tag{25}$$

$$TVB_2 = f\left(TB_q, MG_g, G_3, V_{2,g}, L, U_g\right) \qquad \forall q \in Q \wedge \forall g \in G \tag{26}$$

$$TVB_3 = f\left(L, MM_b, NLE_n Tl_1, Tl_2\right) \qquad \forall b \in BB \wedge \forall n \in NN \tag{27}$$

3.1.6 Constraints

Finally, the constraints of the model are shown in the Table 1. Constraints from *RR1* to *RR9* and *RR15* are applied to the variables to ensure the technical feasibility of vessels. The constraint *RR11* ensures that the vessels do not reach the condition of HSC [High-Speed Craft Code MSC 36(63) and SOLAS, chapter X], as this is not desirable according to the results achieved by previous research (as outlined in the literature review).

Table 1 Constraints applied on the model

RR1			$T < 10$
RR2			$FB > Fbm$
RR3			$G_3 \geq G_2$
RR4	$B \geq$	$TB_q = TB_1$	13.56
		$TB_q = TB_2$	$7 \times 10^{-5} \times PB + 12.47$ if PB * < 82,607
			16 if $82{,}607 \leq PB < 101{,}381$
			13 if $101{,}381 \leq PB$
RR5	$D \geq$	$TB_q = TB_1$	7.15 if $PB \leq 33{,}794$
			$5 \times 10^{-4} \times PB - 5.52$ if $33{,}794 < PB \leq 53{,}600$
RR6		$TB_q = TB_1$	$4.94 < L/B < 7.50$
		$TB_q = TB_2$	$4.26 < B/D < 2.31$
RR7		$TB_q = TB_1$	$1.55 < B/D < 2.31$
		$TB_q = TB_2$	$1.34 < B/D < 2.84$
RR8		$TB_q = TB_1$	$7.85 < B/D < 14.17$
		$TB_q = TB_2$	$8.14 < L/D < 13.20$
RR9		$TB_q = TB_1$	$2.35 < B/T < 3.20$
		$TB_q = TB_2$	$2.38 < B/T < 5.96$
RR10			$N1 \geq N \geq N2$
RR11			$VB < (3.7 \times \nabla^{0.1667} / 0.514)$
RR12		$G_2 \times N \geq$	Cargo1; if $G_{1p} = G_{11}$
			Cargo2; if $G_{1p} = G_{12}$
			Cargo3; if $G_{1p} = G_{13}$
			Cargo4; if $G_{1p} = G_{14}$
			Cargo5; if $G_{1p} = G_{15}$
			Cargo6; if $G_{1p} = G_{16}$
RR13			$(TVU - TVM) / (TVM + TVU) \geq IT$
RR14			$(CU - CMU) / (CMU + CU) \geq IC$
RR15			$TVB \leq NB \times 12$

Note: *PB: measured in horse power (HP).

The constraints *RR10* and *RR12* are necessary to meet the minimum amount of cargo units per year (Cargo1 to Cargo6) and the frequency of service (*N*1, *N*2: yearly trips) imposed for every case-study. Constraints *RR13* and *RR14* ensure the competitiveness of multimodal routes articulated through the Sea Motorway that is reached by operating with a commercial fleet (*IT*, *IC*).This competitiveness must be taken as the minimum which should be reached by the optimised fleet.

3.2 The optimisation framework

Once the mathematical model has been developed, it is necessary to identify, through the analysis of the problem, the most suitable optimisation process to solve it. Thus, considering the nature of the model, we can conclude that it is a mixed-integer and non-linear problem with numerous non-linear constraints. EA are metaheuristics, which have shown an adequate performance in terms of efficiency and effectiveness in this type of problems. As the problem of this work is multi-objective, the NSGA-II (Deb et al., 2002) will be used. In previous works (Martínez et al., 2012), a mono-objective approach of the same problem was also tackled.

4 Application to the case-study

The mathematical model definition is very dependent on the routes and ports selected for the study. For this reason, in this section the general model definition will be applied to the case-study (especially Subsections 3.1.3 to 3.1.6).

For the particular case of the multimodal chains between the Northern Spain and France (see Figure 4), according to García-Alonso and Sánchez-Soriano (2010), the Spanish ports are located in the same province as most of the important population/activity centres of their hinterland, and those centres are the main traffic generators in the Spanish northern coastline (therefore $X_z = 1$, for every route from the north of Spain). For this reason, in this particular case the general 'many to many' model suggested in the methodology (see Section 3.1.3) can be simplified to a 'one to many' model' (Martínez and Alonso, 2011) where the probability of load distribution in the French side (X_d: 0.62, 0.21 and 0.17 for Paris, Lille and Rennes respectively, see Figure 4) was calculated by considering a population criterion (Ng, 2009).

Figure 4 Multimodal chains articulated through Vigo-St.Nazaire and Gijón-St.Nazaire (see online version for colours)

The application of the general expressions (‘many to many’ model) to the case study (‘one to many’ model) implied the origin of routes is unique and coincident to the initial port (m) and which generates all the load ($X_z = 1$) and therefore the door to port distance is zero ($DR^b_{zm} = 0$). This involves that the cost of this stretch is zero ($CMU_{1,1} = 0$, see Section 3.1.4) as well as its time ($TVC_1 = 0$, see Section 3.1.5).

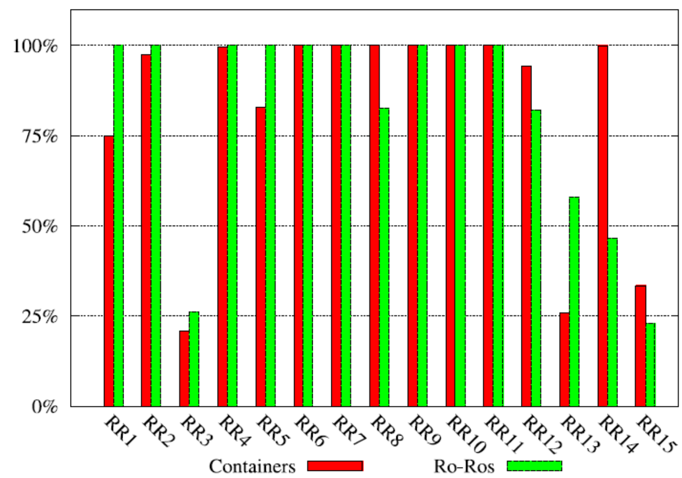
The calculation of TVB_2 (highly conditioned by the cargo handling systems MG_g), for this particular case-study, takes into account the port cranes ($V_{2,1} = 27$ TEUs/h; one crane operating every 37 m of vessel length), port drivers ($V_{2,5} = 8$ trailers/hour per driver, one driver every 17 trucks) and mafis (Ametller, 2007) as cargo handling systems for the cargo units (*PP*). Additionally, by considering the current activity of liner services in these ports, the waiting time for the load in port (from its arrival until the beginning of loading operations) has been assumed as coincident with TVB_3.

Finally, the constraints *RR10* and *RR12* were imposed to meet the minimum amount of cargo units per year and the frequency of service imposed for the case-study, these requirements are demanded by the applicable Normative of Sea Motorway (BOE No. 92, 2006) to Spain and France. For this: $N1 = 740$; $N2 = 384$; Cargo1 = 122,400; Cargo2 = 74,634; Cargo3 = 38,250; Cargo4 = 63,750; Cargo5 = 42,500; Cargo6 = 85,000. For the case-study, *RR13* and *RR14* values ($IT = 0.10$; $IC = 0.14$) were obtained with a Ro-Ro vessel with a cargo capacity of 157 trailers at 30 kn (Martínez and Alonso, 2011).

5 Optimisation process

In order to find the optimal fleet which maximises the opportunities for success of the multimodal chain versus the road, a mathematical model and an optimisation framework have been defined in previous sections. Here, the results obtained after the application of the optimisation framework to the mathematical model are shown and analysed in depth.

Figure 5 Constraints as met by containers and Ro-Ros (see online version for colours)



As aforementioned, consideration of the kind of vessels in studies exploring the competitiveness of the multimodal chain is mainly based on qualitative criteria (Paixao and Marlow, 2002; Woxenius, 2010). Hence, we do not have enough previous information to forecast the competitiveness of the multimodal transport in terms of time or cost based on one kind of vessel versus another. In other words, the dominance of one type of vessel in the investigation and the size of the group of feasible solutions during the optimisation are unknown, and therefore the difficulty of finding feasible solutions for each type of vessel is not known.

Considering the percentages of meeting all constraints (see Figure 5), we can conclude that it is more difficult to find feasible solutions for fleets of containers than Ro-Ro fleets. Hence, in an effort to avoid a premature convergence on a single kind of vessel, three independent optimisation processes will be carried out with the NSGA-II: mixed fleet, a Ro-Ro only fleet and a container only fleet. Because less than 30% of the total vessels evaluated met all of the required, constraints, the solution for the kind of fleet necessary to ensure the competitiveness of multimodal transport against the road is not obvious, and the use of optimisation processes is therefore justified.

The NSGA-II algorithm has been applied with the configuration parameters shown in Table 2. For each experiment, 50 independent runs have been carried out. The hypervolume indicator (Zitzler et al., 2000) is used for the performance comparison; with a unique value this measurement allows comparison of different runs. Given two Pareto fronts, F_1 and F_2, F_1 outperforms F_2, if the hypervolume of F_1 is greater than the hypervolume of F_2. The stop criterion of the EA is based on the number of function evaluations (FEs) and depends on the dimension of the problem. The maximum number of FEs is set to $10{,}000 \cdot n$, where n is the dimension of the problem, in this case 8.

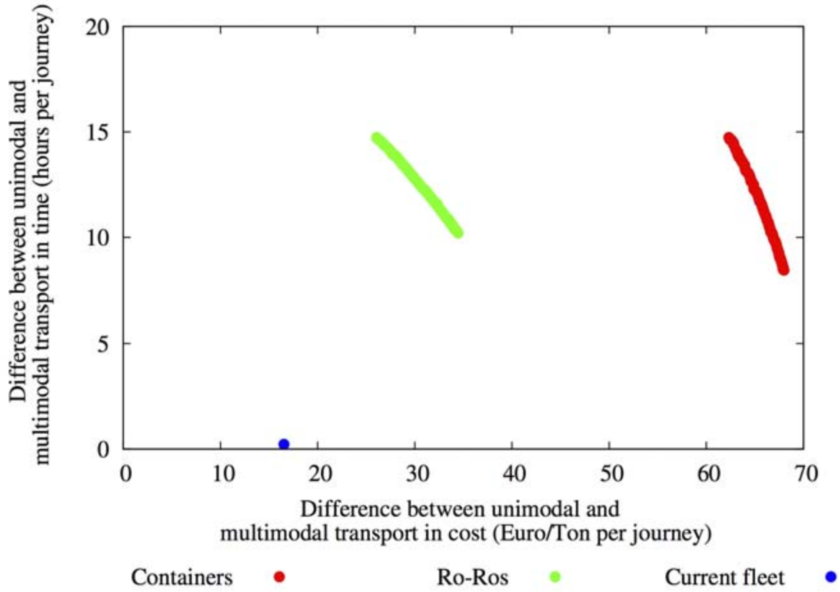
Table 2 Configuration parameters for the NSGA-II algorithm

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

Figure 6 shows the Pareto fronts corresponding to the two independent tests using only containers and only Ro-Ros for the sea motorway: Vigo-St.Nazaire, and the performance of the current fleet which is operating in this route. Pareto fronts are the results of the runs that maximise the hypervolume indicator in each experiment. Each Pareto front contains 100 individuals, i.e., the whole population belongs to the first Pareto front.

The container solutions strongly dominate in terms of the cost to Ro-Ro solutions but not so much in terms of the time. However, despite the fact that container vessels are the most competitive in both runs (with a container only fleet and with a mixed fleet), it is worthwhile analysing the possibilities of Ro-Ro fleets.

Figure 6 Non-dominated solutions for the independent optimisation of containers and Ro-Ros and the performance of the current fleet which covers Vigo-St.Nazaire route (see online version for colours)



5.1 Results assessment

As the hierarchy of attributes considered by cargo owners for the selection of transport in the Western Corridor is mainly based on cost (Feo et al., 2010; Garcia-Menendez and Feo-Valero, 2009) and because a preference for time against cost goes up to a certain value for the transport of small volume of cargo, which often means high added value, (De Jong, 1999; Garcia-Menendez and Feo-Valero, 2009; Nellthorp et al., 2001), the vessels located on the Pareto front with maximum $F1$ value (competitiveness in terms of the cost) have been selected for the analysis. Thus, in Table 3 the features of vessels for Vigo-St.Nazaire are shown. Additionally, the optimisation process has been also carried out for the maritime route of Gijon-St.Nazaire for Ro-Ro fleets in order to assess the affirmations undertaken by Port Authorities. According to the achieved results in the optimisation of Ro-Ro fleets, the operation of two vessels is sufficient to cover Gijon-St.Nazaire, while for Vigo-St.Nazaire three Ro-Ro vessels are necessary (see Table 3). Taking into account the Pareto fronts (see Figure 6) the number of necessary vessels in the fleets (*NB*) is always three for both kinds of vessels and for all possible fleet solutions. Despite the fact that Port Authorities were right, by paying attention to the competitiveness results reached with optimised Ro-Ro fleets for both routes, it can be shown that the results are more favourable (in cost and time) for Vigo-St.Nazaire.

Table 3 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

The differences in time between container and Ro-Ro fleets are small in comparison to the cost difference in the Vigo-St.Nazaire route. This is so despite the fact that the cargo capacity is higher for all containers obtained in the Pareto front ($183 \leq G_2 \leq 210$) than the Ro-Ros ($146 \leq G_2 \leq 162$) due to better arrangement of the cargo space in container vessels ($79.00 \leq L \leq 82.04$) in comparison to Ro-Ros ($118.00 \leq L \leq 123.91$). These results are in accordance with the conclusions obtained by Mbiydzenyuy et al. (2010). However, they diverge from the institutional decisions to support the development of SSS uniquely through Ro-Ros (the Italian Ecobonus or the Spanish Port Normative 33/2010 that supports only Ro-Ros for SSS with a reduction of their port dues).

On the other hand, by analysing the results obtained in Pareto fronts (see Figure5), the optimisation process has found solutions that correct the weak points in both kinds of vessels. Regarding the Ro-Ro type, the moderate service speed ($23.71 \leq VB \leq 28.00$) and the use of unaccompanied trucks (G_{16} by loading with port facilities MG_4 in every solution of the Pareto front) leads to an improvement in the arrangement of the cargo space and finally to a reduction of costs. Thereby, the use of ferries (with accommodation for drivers) in SSS traffic (Bergantino and Bolis, 2008; Morales-Fusco et al., 2012; Woxenius, 2010) would not result appropriate. However, the proposed container fleets (see Figure 6) present a low cargo capacity by operating with port cranes (MG_2 in all cases), which means reduced loading times. This confirms the importance of the speed of loading operations in port for the competitiveness of SSS (Castells i Sanabra, 2009; Martínez and Alonso, 2011; Romana et al., 2010) and therefore the strong influence of the correct sizing of the vessels on it, as the cargo capacity conditions the loading time. This importance increases when the maritime distance decreases, and therefore the size of the fleet will be critical in order to maintain the competitiveness of the multimodal chains through Sea Motorways.

The results obtained not only confirm that it is not necessary to reach a high speed to operate in competitive conditions of time (Castells i Sanabra, 2009; SPIN-HSV Project, 2003–2005) but also that it is not necessary to reach a speed as elevated as expected (less than 20 kn for container vessels) according to the results achieved in other studies (WEST-MOS, 2005–2008, among others). This leads to moderate propulsion power and therefore to the most common arrangements for the engine rooms of vessels (two shaft lines NLE_2 with four diesel engines NMP_4 for Ro-Ros and one shaft line NLE_1 and 1 diesel engine NMP_1 for all containers), and avoids the use of turbines and waterjets (the screw TP_1 was obtained as the most suitable propeller for all obtained vessels due to the fact of that the service speed was always less than 35 kn) which raises the building cost of the vessels and their operating costs.

On the other hand, the cargo units that maximise the competitiveness of multimodal chains for both types of fleet are, as expected, the smallest units studied (G_{11} = TEUs for container vessels and accompanied trucks G_{16} for Ro-Ros). This is because in multimodal transport, this kind of cargo unit can take advantage of the economies of scale on the maritime stretch.

It is important to point out that, despite the differences in the approaches to the problem, we have found similarities among the vessel sizes found for the route Vigo-St.Nazaire (494 nautical miles) and the vessels suggested by other authors. For example, Ng (2009) has considered container vessels with a cargo capacity of 250 TEUs for the SSS traffic between Baltic ports and Western European ports and Ametller (2007) has proposed Ro-Ros of 9500 GT as the most suitable vessels for Barcelona-Civitavecchia (455 nautical miles).

Notwithstanding these results, the fleet which is currently operating in Vigo-St.Nazaire route (although not in Sea Motorway conditions) which is made up of two ro-Ros of 18,978 GT at a service speed of 18 kn, is very far from the optimised fleets (see Table 3).

6 Conclusions

Evidence that the decisions of shipping companies are greatly responsible for the success of multimodal chains may be easily found in previous SSS research, as well as in the Sea Motorways performance in Europe. Despite this evidence, the relationship of issues such as the geographical features of the ‘door to door’ routes, the technical characteristics of the vessels and cargo units, the fleets and their management were seldom addressed from the standpoint of the global competitiveness of the multimodal chains against the road.

This work attempts to contribute to filling this gap by providing an optimisation model able to define those technical and operative features of the fleet, which maximise opportunities for the success of multimodal transport in terms of cost and time. Thereby, this work introduces a general method for the construction of the model; subsequently the method is applied to obtaining the optimisation model for the study case: Vigo-St.Nazaire.

From the analysis of the optimisation process for the study case, we can point out that it is extremely difficult to find container fleets to serve on multimodal chains that are able to achieve the minimum competitiveness required in time (constraint *RR13*). This is mainly due to the high cargo capacity of these vessels, which means longer port times per vessel. The opposite happens with satisfying the minimum competitiveness required in cost (constraint *RR14*). Despite this, a container fleet with three vessels of 210 TEUs of cargo capacity has been obtained as the best solution (considering both attributes, cost and time, simultaneously) for transport chains through the Vigo-St.Nazaire route. Regarding the Ro-Ros, the most competitive fleet identified for this route, has three vessels with a cargo capacity of 162 trucks without a tractor head. The difference between the two fleets is relevant to the competitiveness of the multimodal chains in terms of cost (the cost of the Ro-Ro fleet is nearly twice as high as the container fleet) but less so in terms of time (a 17% advantage for the Ro-Ro fleet). Notwithstanding the great difficulty in finding feasible container fleets, the results obtained in this work suggest the use of containers is preferable to Ro-Ros for SSS in ideal port conditions and contradicts some national rules of European countries which support only this kind of vessel for SSS.

Additionally, the required speed for the shipping is not as high as expected for any fleet on Vigo-St.Nazaire, and it is closer to the generalised estimations provided by previous studies. This is mainly due to the greater influence of the service speed for SSS on cost than on time. Additionally, the time invested in port operations is critical for multimodal chain competitiveness, this reality leads to the fact of the specified vessels have a moderate size (especially the containers for which the weakest point is the time) which permits reduced loading times. It is also noteworthy that the type of cargo units found is the smallest for each kind of vessel. For the Ro-Ros, the cargo unit selected (trucks without master head) rules out ferries as suitable vessels for the Sea Motorways. Despite the fact that this parameter cannot be controlled by the transport responsible, this conclusion can help to focus the client's search.

On the other hand, once the optimal fleet with its operative and technical features has been defined, future studies should focus efforts on the assessment of freight price with the variations of uncontrollable inputs over time such as the demand (utilisation ratio of vessels) and kinds of cargo units. For this, the evolution of the demand between France and Spain should be evaluated.

Finally, note that the size and number of the vessels specified for the optimised Ro-Ro fleet is very different from the Ro-Ro fleet, which is currently covering the Vigo-St.Nazaire route and that this number of vessels is higher than those obtained for the Gijón-St.Nazaire route. This could be one of the reasons for the lack of feasibility of the Sea Motorway announced by the shipping company and reaffirms, partially, the Port Authorities declarations about the different activity of both Sea Motorways. Thereby, the results confirm the risk taken when technical and operating assumptions are applied to multimodal transport analysis without paying attention to the relationships which exist among them.

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