Appendix A

Appendix

A.1 Kite Propulsion Force Data Input

Table A.1: Data input for a kite of 160 m^2

Parameter	Value	Unit
a	50	
b	-40	
c	-10	
d	15	
γ_P	45°	
ρ_A	1.204	kg/m^3
A_D	160	m^2
c_W	0.5	

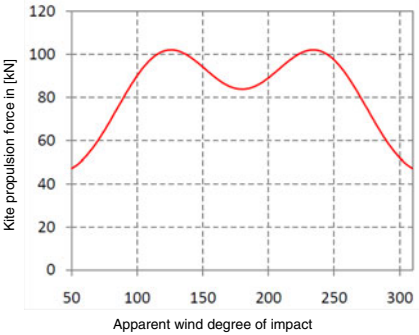

Figure A.1: Kite propulsion force gradient

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A.2 Ship Data

Table A.2: Ship data

Ship name	Container capacity [TEU]	Length [m]	Breadth [m]	Height [m]	Draft [m]
Rafaela	4,100	281	32.3	20	12
Alicante	5,500	270.4	40	21.7	13.5
Moliere	6,550	300	40	24.2	14.5
Hamburg	8,580	334	42.8	24.8	14.61
Laetitia	9,661	350	42.8	27.3	15
Buenos Aires	14,000	365.5	51.2	29.2	16

Ship name	Breadth of cargo [m]	Depth of cargo [m]	Total height of cargo and ship above water [m]	Hull heigth above water [m]	Heigth of Cargo above water [m]
Rafaela	32.3	252.9	38.89	8	18.82
Alicante	40	243.36	40.59	8.2	18.82
Moliere	40	270	43.09	9.7	18.82
Hamburg	42.8	300.6	46.38	10.19	21.51
Laetitia	42.8	315	48.88	12.3	21.51
Buenos Aires	51.2	328.95	54.18	13.9	24.2

Ship name	Displacement [t]	Radius of gyration [ft]	Engine power [KW]	Consumption coefficient	Power coefficient
Rafaela	72,340	230.48	51,390	0.00028	0.895
Alicante	95,786	221.78	42,140	0.00031	0.886
Moliere	112,361	246.06	57,866	0.00026	0.794
Hamburg	128,445	273.95	72,240	0.00023	1.044
Laetitia	135,887	287.07	68,640	0.00024	1.053
Buenos Aires	171,866	299.79	72,240	0.00024	1.164

Ship name	Engine efficiency	Propulsion efficiency	Base consumption [mt/d]	Charter rate [US$/d]	Service speed [kn]
Rafaela	0.99	0.7	185.2	23,000	25.4
Alicante	0.99	0.7	152.9	30,000	23.2
Moliere	0.99	0.7	208.4	35,000	25.6
Hamburg	0.99	0.7	252.9	45,000	25.6
Laetitia	0.99	0.7	247.3	51,000	25.3
Buenos Aires	0.99	0.7	262.2	72,000	24.1

A.3 Wave Resistance Data Input

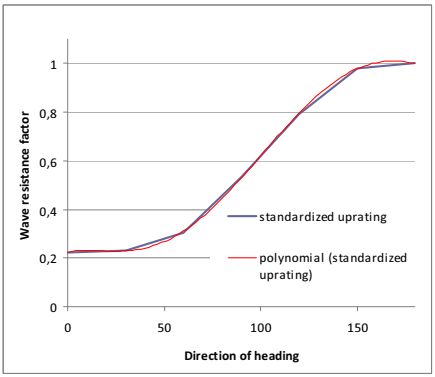

Figure A.2: Wave resistance factor according to (Yaozong 1989, p. 19-20)

A.4 Great Circle Navigation Formulas

We constructed our network similar to the way as Lee et al. (2002) described in his approach, in the following the generally known great circle navigation formulas that we applied in our Environmental-Routing algorithm are given. All values are in radians. A Course $C_{1,2}$ from a point 1 to any other point along a great circle route is obtained as follows:

$$if((lon_1 - lon_2) < 0) then$$
$$C_{1,2} = \arccos\left(frac\sin(Lat_2) - \sin(lat_1)\cos(D_{1,2})\sin(D_{1,2}\cos(lat_1))\right)$$
$$else$$
$$C_{1,2} = 2\pi - \arccos\left(frac\sin(Lat_2) - \sin(lat_1)\cos(D_{1,2})\sin(D_{1,2}\cos(lat_1))\right)$$

where $D_{1,2}$, the great circle distance between two point is calculated by the formulation.

$$D_{1,2} = \arccos\left(\sin(lat_1)sin(lat_2) + cos(lat_1)cos(lat_2)\cos(lon_2 - lon_1)\right)$$

Figure A.3: Determination of a great circle route

A.5 Computational Tests - Changing Revenue

Table A.3: Evaluating the effect of changing revenues

Test set	Number of Harbours	Revenue coefficient	Available number of a given type of ship:												Objective function value in thousands
			Rafaela	Rafaela wS	Alicante	Alicante wS	Moliere	Moliere wS	Hamburg	Hamburg wS	Laetitia	Laetitia wS	Buenos Aires	Buenos Aires wS	
3sSnS	10	0.4		3		4		5							11,026
3sSnS	10	0.5		4		4		3							13,934
3sSnS	10	0.6		3		4		5							17,722
3sSnS	16	0.4		5		5		5							40,942
3sSnS	16	0.5		5		5		5							50,531
3sSnS	16	0.6		5		5		5							57,205
3sSnS	23	0.4		5		5		5							34,525
3sSnS	23	0.5		5		5		5							40,070
3sSnS	23	0.6		5		5		5							55,560
3sSnS	33	0.4		5		5		5							35,571
3sSnS	33	0.5		5		5		5							47,399
3sSnS	33	0.6		5		5		5							54,103
3sSwS	10	0.4	4		3		4								11,782
3sSwS	10	0.5	4		4		3								14,435
3sSwS	10	0.6	4		4		4								18,153
3sSwS	16	0.4	5		5		5								42,341
3sSwS	16	0.5	5		5		5								52,010
3sSwS	16	0.6	5		5		5								64,089
3sSwS	23	0.4	5		5		5								37,490
3sSwS	23	0.5	5		5		5								45,680
3sSwS	23	0.6	5		5		5								56,170
3sSwS	33	0.4	5		5		5								42,392
3sSwS	33	0.5	5		5		5								51,074
3sSwS	33	0.6	5		5		5								64,470
3lSwS	10	0.4							2		5		4		11,962
3lSwS	10	0.5							4		4		3		14,450
3lSwS	10	0.6							5		4		4		18,533
3lSwS	16	0.4							5		5		5		41,389
3lSwS	16	0.5							5		5		5		61,644
3lSwS	16	0.6							5		5		5		63,589
3lSwS	23	0.4							5		5		5		45,587
3lSwS	23	0.5							5		5		5		54,586
3lSwS	23	0.6							5		5		5		63,391
3lSwS	33	0.4							5		5		5		37,643
3lSwS	33	0.5							5		5		5		46,051
3lSwS	33	0.6							5		5		5		51,701
3lSnS	10	0.4								4		4		4	11,242
3lSnS	10	0.5								5		4		2	14,442
3lSnS	10	0.6								4		3		4	17,242
3lSnS	16	0.4								5		5		5	38,904
3lSnS	16	0.5								5		5		5	59,704
3lSnS	16	0.6								5		5		5	61,895
3lSnS	23	0.4								5		5		5	41,117
3lSnS	23	0.5								5		5		5	43,992
3lSnS	23	0.6								5		5		5	61,515
3lSnS	33	0.4								5		5		5	33,778
3lSnS	33	0.5								5		5		5	45,723
3lSnS	33	0.6								5		5		5	51,063

Parameter settings: Season 4, fuel price 650$ per mt, charter rate coefficient 4.9, number of ships of each type available 5, maximum allowed delivery time for cargo obtained with 5kn and number of iterations set to 25

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