Journal of Maritime Research, Vol. VII. No. 2, pp. 49-62, 2010

ISSN: 1697-4840

ANALYSIS OF THE TURNING CIRCLE MANOEUVRE FROM THE POINT OF VIEW OF AN EFFICIENT MANAGING OF THE MAIN ENGINE

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Received 27 January 2010; in revised form 08 February 2010; accepted 23 June 2010

Abstract

The purpose of this paper is to study the influence of the 360 deg turn in the economy of the voyage and to find out the maximum efficiency by means of the main engine's procedure. Moreover the additional cost of the turning circle manoeuvre out of the whole of sea passage is also studied. The simulation is carried out on two types of vessels: a SUEZMAX of 150,000 dwt and an AFRAMAX of 100,000 dwt.

Keywords: Turning circle manoeuvre (turn of 360 deg). Consumption/speed relationship. Economic speed. Optimum speed. Costs: Percentage of turning circle manoeuvre out of the whole sea passage.

INTRODUCTION

One of the more costly encounter avoidance manoeuvre concerning the economy of the vessel is the turn of 360 deg. This manoeuvre may be carried out when our vessel is to be kept far away from the other vessel or when the other vessel does not steer according to the COLREG and hence force our vessel to alter her heading to starboard up to a complete a turn of 360 deg.

The research intends to find the more economical speed of approach so that the consumption of petrol during the turn of 360 deg be minimum. Moreover the optimum speed of approach to reduce the total cost (consumption of petrol and hire) to a

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minimum is calculated. The curves and data representing the economic and optimum speed of approach are calculated by means of interpolation methods (spline and least squares) starting from the real data of the ship sea trials and engine shop trials (Evanas, 1990).

The time spent in tracking the turning circle will depend on the speed of approach, the loading condition or draft, the under keel water, wind, currents and other factors (Clark, 2005). However this research is not to take into account all these parameters. In this way the only variable used in the mathematical calculation is the speed of approach and the vessels are considered in full load condition.

SUEZMAX	AFRAMAX
Type of ship: Tanker	Type of ship: Tanker
150.000 dwt	100.000 dwt
Loaded condition	Loaded condition
Lenght: 274.2 M.	Lenght (O.A.): 246.8 M
Breadth (MLD.): 48.0 M.	Breadth (MLD.): 42.0 M

At the end of this paper a calculation is carried out with regard to the percentage of fuel consumed during the turning circle manoeuvre out of the total fuel consumed during a particular sea passage. In addition the percentage of the turning circle manoeuvre out of the whole sea-passage in respect of fuel consumption and costs will be determined.

TURNING CIRCLE

During the sea trials and especially in the manoeuvring tests, the ship performance is considered with the rudder is deflected and held at a fixed maximum angle, both to starboard and port side. Then it starts a path called turning circle which is divided into three distinct phases (SNAME, 1990):

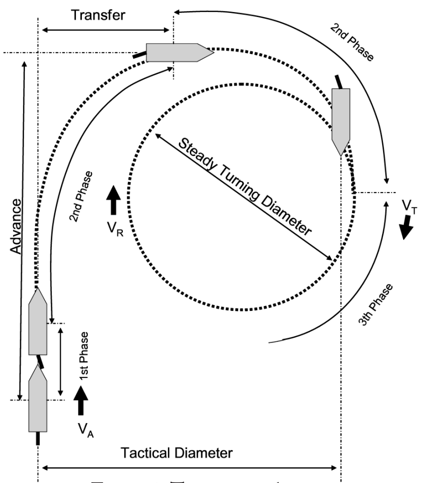

Figure 1: Turning circle.

First phase: Taking into consideration that the vessel is advancing on a straight track, this phase starts when the rudder begins to deflect and is to finish when it has reached a fixed angle (usually the maximum angle). In this any other angle smaller than maximum is not considered since it would be uneconomical according to.

Second phase: During this phase the deflection of the rudder remains unalterable and the forces and resistances affecting the wet surface make the vessel fall to the same side than the deflection of the rudder. The vessel is also undergoing a progressive loss of velocity. Further the diameter of the turning circle is decreasing.

Third phase: The dynamic equilibrium of turning forces and resistances affecting the vessel is reached. The speed is reduced to around 1/3 of the speed of approach and is kept unalterable from the time worth. The vessel keeps turning in a circle with a steady diameter.

In addition to the different phases, the following information concerning the turning circle should be taken into account:

Advance: It is the distance in the prolongation of original path that vessel moves to alter the heading 90 deg.

Transfer: It is the lateral distance that the vessel moves from the original path whilst tracking the turning circle. In figure 1 it is shown the transfer for altering the heading 90 deg.

Tactical diameter: It is the transfer to alter the heading 180 deg.

Steady turning diameter: After the establishment of the third phase, the ship settles down to a turn of constant diameter as outlined in fig. 1.

Velocity of approach (V_A): It is the speed of the vessel at the beginning of the first phase.

Velocity on steady turn (V_T): It is the speed reached in the third phase.

Speed remainder (V_R): It is the speed of the vessel at any stage of the turning circle. In this research the speed remainder will be the velocity of the ship once her heading is altered 360°.

Before analyzing the economy of the turning circle manoeuvre, it is necessary to know the time elapsed up to the heading alteration of 360° (it will be mentioned as 'manoeuvring time' in this paper). This time is obtained in the ship trials for a velocity of approach similar to the cruise speed. Figure 2 shows the time necessary for the Suezmax and Aframax vessels to alter the heading 90°, 180°, 270° and 360° at a velocity of approach equal to the cruise speed. Logically the Suezmax spent more

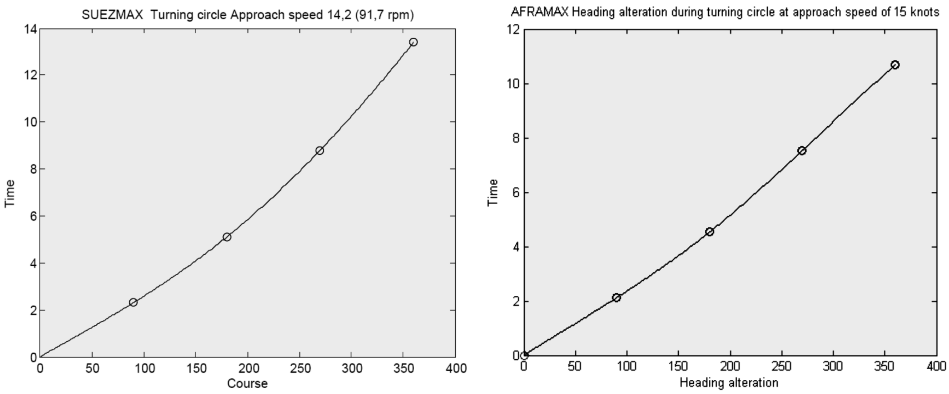

Figure 2: Heading alteration during the turning circle.

time than the Aframax due to the differences between the displacements. The research is carried out without taking into account additional effects such as shallow waters, wind, swell or current.

The following proximate formula is used to know the time elapsed up to the heading alteration of 360° (Crane, 1989):

$$t_B = t_A \cdot \left(\frac{L_B}{L_A} \cdot \frac{V_A}{V_B} \right) \quad (1)$$

Where:

V_A is speed of reference for vessel A
t_A is time spent in effecting the turning circle manoeuvre at velocity of approach of V_A
V_B is speed of reference for vessel B
t_B is time spent in effecting the turning circle manoeuvre at velocity of approach of V_B
L_A is lenght of A
L_B is lenght of B

$$t = t_A \cdot \left(\frac{V_A}{V} \right) \quad (2)$$

Where:

V_A is speed of reference for the vessel A (cruise speed)
t_A is time spent in effecting the turning circle manoeuvre at velocity of approach of V_A
V is any velocity of approach
t is time spent in effecting the turning circle manoeuvre at velocity of approach of V

Table 1 shows the results in the calculation of the manoeuvring time in minutes by means of the application of formulae (2):

Figure 3 shows the approximation of the formula (2) by comparison of the real time spent in altering the heading and the time obtained from the formula:

Velocity Of Approach (KNOTS)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Suezmax Manoeuvring Time (MIN)	181,5	90,8	60,5	45,4	36,3	30,3	25,9	22,7	20,2	18,1	16,5	15,1	14	13	12,1	11,3	10,7
Aframax Manoeuvring Time (MIN)	160,1	80	53,4	40	32	26,7	22,9	20	17,8	16	14,6	13,3	12,3	11,4	10,7	10,0	9,4

Table 1: Time spent during the turn of 360 deg at different velocity of approach.

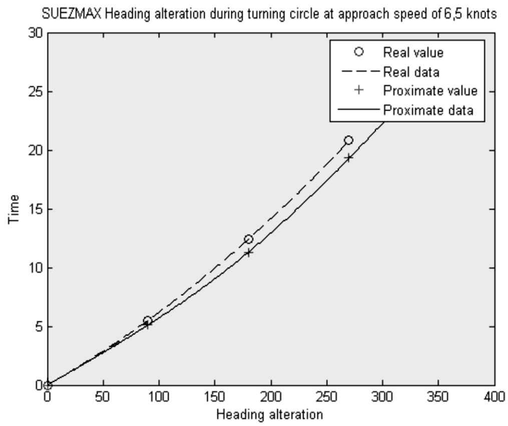

Figure 3: Comparison between real and proximate data of heading alteration during the turning circle.

OPTIMAL SPEED

The ship who sails at economic speed achieves the minimum consumption of petrol per unity of time.

The engine's shop trials provide us with real data on the specific consumption of petrol in gr/kw/h at different BHP. On the other hand, the necessary BHP to provide the vessel with a specific speed whilst sailing may be obtained from the ship's sea trials. Sometimes the speed trials may also show the consumption at different sailing speeds (Watson, 1998).

Hence the relationship between the speed and the consumption is obtained from the real results of engine's shop trials and ship's sea trials by means of interpolation systems as spline and least squares. Nevertheless, the consumption of the main engine is calculated for an output higher than 50% (around 12 knots of speed in the ships tested) and thus the values below this percentage lack the required scientific rigour. In figure 4 and table 2 the approximate results obtained under interpolation are shown.

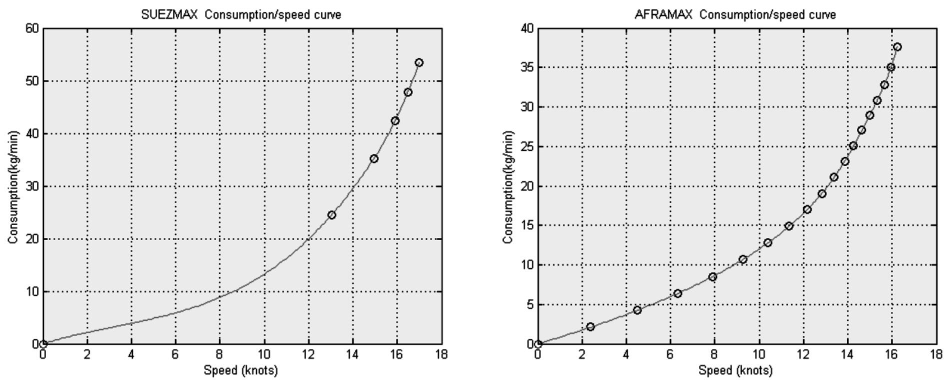

Figure 4: Curves of fuel consumption for vessels tested

Velocity Of Approach (KNOTS)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Suezmax Consumption (KG/MIN)	1,2	2,2	3	3,9	4,8	5,9	7,2	8,8	10,8	13,2	16,3	19,9	24,3	29,5	35,6	43,3	53,4
Aframax Consumption (KG/MIN)	0,85	1,7	2,7	3,7	4,8	6	7,2	8,6	10,2	12	14,1	16,5	19,6	23,8	29	35,5	49,6

Table 2: Fuel consumption at different speeds.

In figures 5 and 3 the kilos of petrol consumed during the turning circle performance at different speeds of approach are shown.

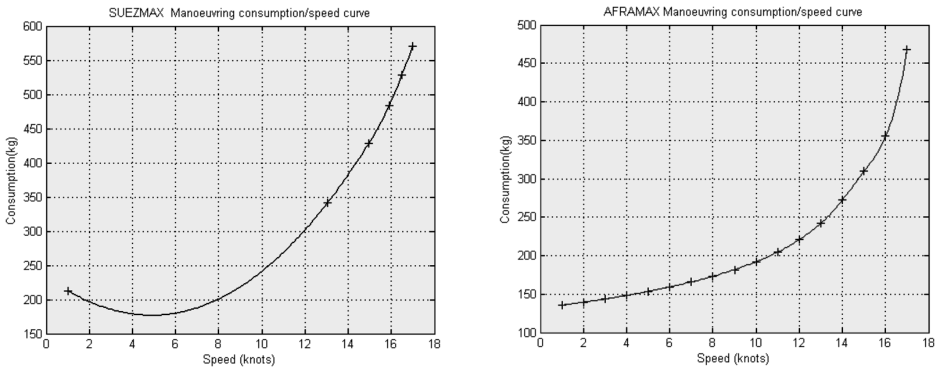

Figure 5: Fuel consumption during turning circle manoeuvre at different velocities of approach.

Speed Of Approach (KNOTS)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Suezmax Manoeuvring Consumption (KG)	213	196	184	177	175	178	186	199	217	240	269	302	340	383	431	491	570
Aframax Manoeuvring Consumption (KG)	135,8	139,5	143,7	148,3	153,5	159	166	173	182	192	205	221	242	272	310	355	468

Table 3: Fuel consumption during the turning circle manoeuvre at different velocities of approach.

OPTIMUM SPEED

In the computation of the optimum speed the hire of the ship in addition to the petrol consumed and its price is considered. Thus the ship sailing at optimum speed achieves the minimum cost in bunker and hire per time (Laurence, 1984).

The results of the simulation are shown in the following information:

— Graphics of cost, hire and speed of approach for the turning circle manoeuvre taking into account two different prices of fuel-oil (figure 6)

— Data of time and consumption of the turning circle manoeuvre as well as the cost at bunker price of 456 USD per metric tonne for three different daily hires. The estimated optimum speed is marked (tables 4 and 5)

— Graphics of cost, price of bunker and speed of approach for the turning circle manoeuvre taking into account two different hire (figure 7)

— Data of time and consumption of the turning circle manoeuvre as well as the cost at three different bunker prices for four different daily hires. It is marked the estimated optimum speed (tables from 6 to 9)

ZUEZMAX

ZUEZMAX

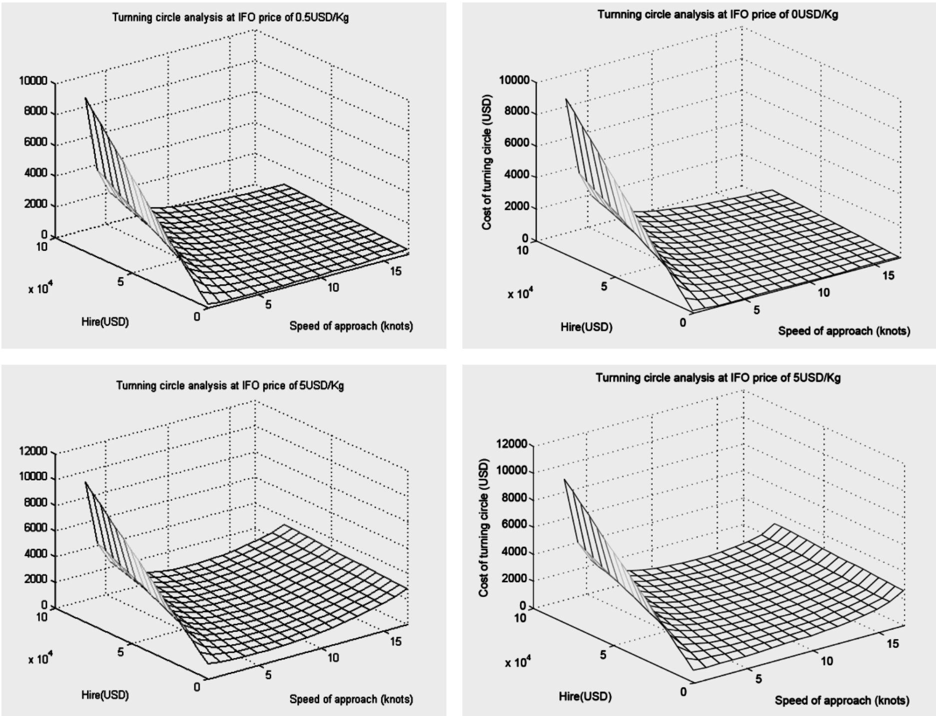

Figure 6: Manoeuvring cost depending on the speed of approach and hire.

Speed Of Approach (Knots)	Manoeuvring Time(Min)	Manoeuvring Consumption (Kg)	Manoeuvring Cost (Usd) Hire: 6,000 Usd	Manoeuvring Cost (Usd) Hire: 30,000 Usd	Manoeuvring Cost (Usd) Hire: 61,000 Usd
1	181,54	212,91	853,50	3879,17	7787,32
2	90,77	195,90	467,54	1980,37	3934,45
3	60,51	183,89	335,99	1344,55	2647,27
4	45,39	176,91	269,78	1026,19	2003,23
5	36,31	174,94	231,06	836,19	1617,82
6	30,26	177,99	207,23	711,51	1362,87
7	25,93	186,06	192,90	625,14	1183,45
8	22,69	199,15	185,36	563,57	1052,09
9	20,17	217,25	183,11	519,30	953,54
10	18,15	240,38	185,25	487,82	878,63
11	16,50	268,51	191,21	466,27	821,55
12	15,13	301,67	200,60	452,73	778,41
13	13,96	339,84	213,15	445,90	746,53
14	12,97	383,04	228,69	444,81	723,97
15	12,10	431,25	247,08	448,79	709,33
16	11,35	491,01	271,18	460,28	704,54
17	10,68	569,82	304,33	482,31	712,21

Table 4: Cost of turning circle manoeuvre for SUEZMAX at IFO price of 0.456 USD/kg.

Speed Of Approach (Knots)	Manoeuvring Time(Min)	Manoeuvring Consumption (Kg)	Manoeuvring Cost (Usd) Hire: 6,000 Usd	Manoeuvring Cost (Usd) Hire: 30,000 Usd	Manoeuvring Cost (Usd) Hire: 61,000 Usd
1	160,17	135,79	729,30	3398,80	6846,90
2	80,09	139,48	397,29	1732,04	3456,09
3	53,39	143,66	287,97	1177,80	2327,17
4	40,04	148,32	234,48	901,85	1763,88
5	32,03	153,47	203,46	737,36	1426,98
6	26,70	159,22	183,83	628,75	1203,44
7	22,88	165,71	170,90	552,26	1044,85
8	20,02	173,14	162,37	496,06	927,07
9	17,80	181,79	157,05	453,66	836,78
10	16,02	192,07	154,32	421,27	766,08
11	14,56	204,66	153,99	396,68	710,14
12	13,35	220,68	156,24	378,70	666,04
13	12,32	242,13	161,75	367,09	632,33
14	11,44	272,18	171,79	362,46	608,76
15	10,68	309,71	185,72	363,69	593,56
16	10,01	354,99	203,59	370,43	585,94
17	9,42	467,63	252,50	409,53	612,36

Table 5: Cost of turning circle manoeuvre for AFRAMAX at IFO price of 0.456 USD/kg.

ZUEZMAX ZUEZMAX

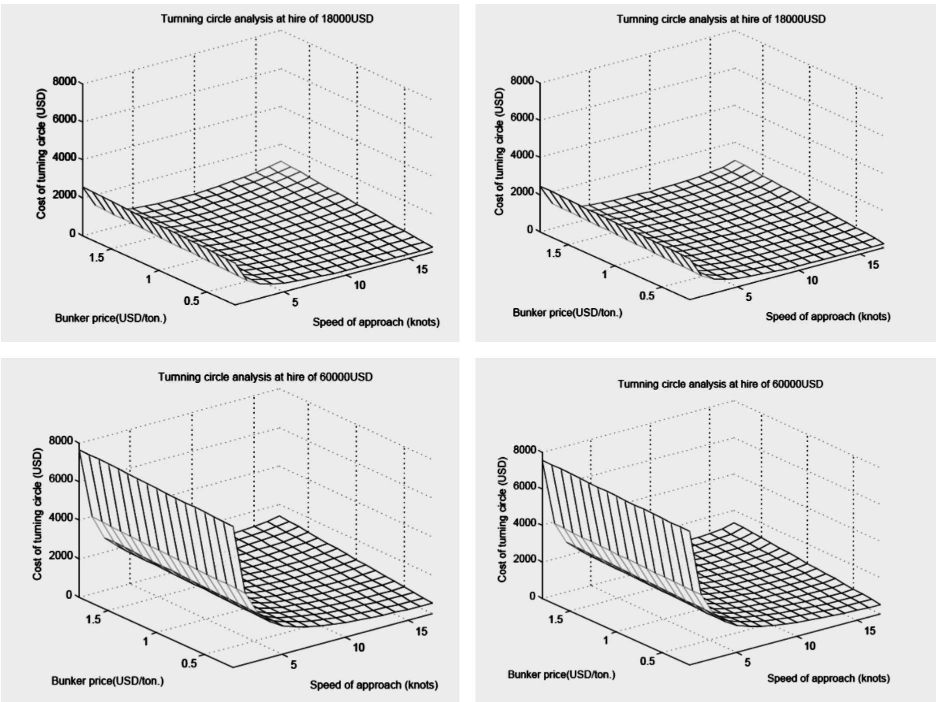

Figure 7: Manoeuvring cost depending on the speed of approach and bunker price.

Velocity Of Approach (Knots)	Manoeuvring Time(Min)	Manoeuvring Consumption (Kg)	Manoeuvring Cost (Usd) At Bunker Price Of 0,3 Usd/Kg	Manoeuvring Cost (Usd) At Bunker Price Of 0,5 Usd/Kg	Manoeuvring Cost (Usd) At Bunker Price Of 1 Usd/Kg
9	20,17	217,25	317,31	360,77	469,39
10	18,15	240,38	299,04	347,11	467,30
11	16,50	268,51	286,85	340,55	474,81
12	15,13	301,67	279,61	339,94	490,77
13	13,96	339,84	276,51	344,48	514,40
14	12,97	383,04	277,00	353,61	545,12
15	12,10	431,25	280,66	366,91	582,53
16	11,35	491,01	289,13	387,33	632,84
17	10,68	569,82	304,43	418,40	703,31

Table 6: Cost of turning circle manoeuvre for SUEZMAX at hire of 18,000 USD daily.

Velocity Of Approach (Knots)	Manoeuvring Time(Min)	Manoeuvring Consumption (Kg)	Manoeuvring Cost (Usd) At Bunker Price Of 0,3 Usd/Kg	Manoeuvring Cost (Usd) At Bunker Price Of 0,5 Usd/Kg	Manoeuvring Cost (Usd) At Bunker Price Of 1 Usd/Kg
12	15,13	301,67	720,85	781,18	932,02
13	13,96	339,84	683,81	751,78	921,70
14	12,97	383,04	655,21	731,82	923,33
15	12,10	431,25	633,65	719,90	935,52
16	11,35	491,01	620,06	718,27	963,77
17	10,68	569,82	615,90	729,86	1014,77

Table 7: Cost of turning circle manoeuvre for SUEZMAX at hire of 60,000 USD daily.

Velocity Of Approach (Knots)	Manoeuvring Time(Min)	Manoeuvring Consumption (Kg)	Manoeuvring Cost (Usd) At Bunker Price Of 0,3 Usd/Kg	Manoeuvring Cost (Usd) At Bunker Price Of 0,5 Usd/Kg	Manoeuvring Cost (Usd) At Bunker Price Of 1 Usd/Kg
12	13,35	220,68	233,05	277,18	387,52
13	12,32	242,13	226,65	275,07	396,14
14	11,44	272,18	224,66	279,10	415,19
15	10,68	309,71	226,39	288,33	443,19
16	10,01	354,99	231,63	302,63	480,12
17	9,42	467,63	258,06	351,59	585,40

Table 8: Cost of turning circle manoeuvre for AFRAMAX at hire of 18,000 USD daily.

Velocity Of Approach (Knots)	Manoeuvring Time(Min)	Manoeuvring Consumption (Kg)	Manoeuvring Cost (Usd) At Bunker Price Of 0,3 Usd/Kg	Manoeuvring Cost (Usd) At Bunker Price Of 0,5 Usd/Kg	Manoeuvring Cost (Usd) At Bunker Price Of 1 Usd/Kg
12	13,35	220,68	622,35	666,49	776,83
13	12,32	242,13	586,00	634,43	755,49
14	11,44	272,18	558,35	612,79	748,88
15	10,68	309,71	537,83	599,77	754,63
16	10,01	354,99	523,61	594,60	772,10
17	9,42	467,63	532,86	626,39	860,20

Table 9: Cost of turning circle manoeuvre for AFRAMAX at hire of 60,000 USD daily.

PREVIOUS DECELERATION AND SUBSEQUENT ACCELERATION

As shown in figure 8 the ship suffers a reduction of the speed from V_C to V_A in an interval of time T_D before the manoeuvre; a loss of speed from V_A to V_R during the manoeuvre and an increase of the speed from V_R to V_C after the manoeuvre. In the simulation the changes of velocity are instantaneous and the time during the deceleration (T_D) and the acceleration (T_A) is not considered.

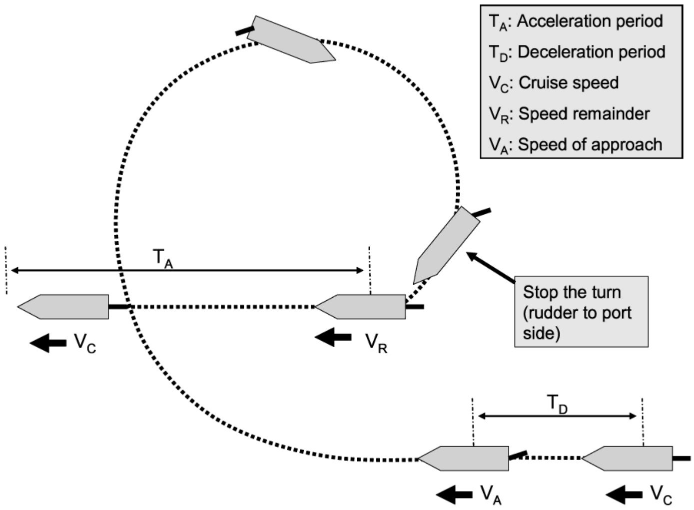

Figure 8: Details of deceleration and acceleration of the ship.

It would be predicted that the ship reaches the steady phase after the turn of 360 deg and, consequently, the speed remainder would be equal to the speed in the steady turn. This speed may be calculated by means of formulae related to the basic ship designs according to Lyster-Knights (Lyster, 1979).

PERCENTAGE OF TURNING CIRCLE MANOEUVRE OUT OF THE WHOLE SEA-PASSAGE WITH REGARD TO PETROL CONSUMPTION AND COSTS

Starting from formulae (1) and (2) a proximate way of calculating the percentage of petrol consumed during the turning circle manoeuvre out of the whole sea passage is obtained:

$$Percentage = 100 \cdot \frac{t_C \cdot V_C \cdot V_A}{60 \cdot D \cdot V_B} \cdot \frac{L}{L_C} \cdot \frac{C_B}{C_A} \qquad (3)$$

$$Percentage = 100 \cdot \frac{t_A \cdot V_A^2}{60 \cdot D \cdot V_B} \cdot \frac{C_B}{C_A} \qquad (4)$$

Where:

L is lenght in meters of analyzed ship
L_C is lenght in meters of ship C
t_C is time in minutes for the ship C to turn 360 deg at velocity of approach V_C.
V_B is velocity of approach in knots for analyzed ship
C_B is consumption in kg/min for analyzed ship at speed V_B
V_A is cruise speed in knots of analyzed ship
D is distance of sea passage in miles
C_A is consumption in kg/min for analyzed ship at cruise speed V_A

The results are obtained in formula (3) by using details of a ship other than the analyzed one.

Moreover the cost of turning circle manoeuvre out of the sea passage may be approximately calculated:

$$Percentage = 100 \cdot \frac{t_C \cdot V_C \cdot V_A}{60 \cdot D \cdot V_B} \cdot \frac{L}{L_C} \cdot \left(1 + \frac{C_B}{C_A}\right) \tag{5}$$

$$Percentage = 100 \cdot \frac{t_A \cdot V_A^2}{60 \cdot D \cdot V_B} \cdot \left(1 + \frac{C_B}{C_A}\right) \tag{6}$$

The following tables (tables 10 to 15) show the extra consumption and extra cost of the turning circle manoeuvre on the whole sea passage. The cost of passage is calculated for different hires, different velocities of approach and a fixed bunker price of 0,456 USD/kg.

Speed Of Approach (Knots)	Manoeuvring Time (Min)	Consumption (Kg/Min)	Fuel Cost (Usd/Kg)	Distance: 500 miles	Distance: 1000 miles	Distance: 2000 miles	Distance: 3000 miles	Distance: 4000 miles
				%	%	%	%	%
8	20,02	8,6478	0,4560	0,381753%	0,190877%	0,095438%	0,063626%	0,047719%
9	17,80	10,2146	0,4560	0,400817%	0,200408%	0,100204%	0,066803%	0,050102%
10	16,02	11,9915	0,4560	0,423488%	0,211744%	0,105872%	0,070581%	0,052936%
11	14,56	14,0553	0,4560	0,451247%	0,225624%	0,112812%	0,075208%	0,056406%
12	13,35	16,5334	0,4560	0,486573%	0,243287%	0,121643%	0,081096%	0,060822%
13	12,32	19,6521	0,4560	0,533867%	0,266933%	0,133467%	0,088978%	0,066733%
14	11,44	23,7908	0,4560	0,600134%	0,300067%	0,150033%	0,100022%	0,075017%
15	10,68	29,0049	0,4560	0,682885%	0,341442%	0,170721%	0,113814%	0,085361%
16	10,01	35,4613	0,4560	0,782712%	0,391356%	0,195678%	0,130452%	0,097839%
17	9,42	49,6331	0,4560	1,031074%	0,515537%	0,257768%	0,171846%	0,128884%

Table 10. AFRAMAX - Percentage of the consumption of turning circle manoeuvre on the total consumption of voyage at cruise speed of 13 knots.

Speed Of Ap. (Knots)	Manoeuvring Time (Min)	Consumption (Kg/Min)	Fuel Cost (Usd/Kg)	Hire (Usd)	Distance: 500 miles	Distance: 1000 miles	Distance: 2000 miles	Distance: 3000 miles	Distance: 4000 miles
					%	%	%	%	%
9	17,80	10,2146	0,456	18000	1,0585983%	0,5292991%	0,2646324%	0,1764254%	0,1323205%
10	16,02	11,9915	0,456	18000	0,9977308%	0,4988654%	0,2494165%	0,1662813%	0,1247123%
11	14,56	14,0553	0,456	18000	0,9545342%	0,4772671%	0,2386180%	0,1590821%	0,1193129%
12	13,35	16,5334	0,456	18000	0,9272790%	0,4636395%	0,2318047%	0,1545398%	0,1159061%
13	12,32	19,6521	0,456	18000	0,9166942%	0,4583471%	0,2291586%	0,1527757%	0,1145830%
14	11,44	23,7908	0,456	18000	0,9260694%	0,4630347%	0,2315023%	0,1543382%	0,1157549%
15	10,68	29,0049	0,456	18000	0,9523478%	0,4761739%	0,2380715%	0,1587178%	0,1190396%
16	10,01	35,4613	0,456	18000	0,9950014%	0,4975007%	0,2487342%	0,1658264%	0,1243711%
17	9,42	49,6331	0,456	18000	1,1475541%	0,5737770%	0,2868699%	0,1912507%	0,1434396%

Table 11. AFRAMAX -Percentage of the cost of turning circle manoeuvre on the total cost of voyage at cruise speed of 13 knots.

Speed Of Ap. (Knots)	Manoeuvring Time (Min)	Consumption (Kg/Min)	Fuel Cost (Usd/Kg)	Hire (Usd)	Distance: 500 miles	Distance: 1000 miles	Distance: 2000 miles	Distance: 3000 miles	Distance: 4000 miles
					%	%	%	%	%
9	17,80	10,2146	0,456	60000	0,8574333%	0,4287166%	0,2143444%	0,1428994%	0,1071757%
10	16,02	11,9915	0,456	60000	0,7851877%	0,3925938%	0,1962842%	0,1308589%	0,0981453%
11	14,56	14,0553	0,456	60000	0,7280588%	0,3640294%	0,1820029%	0,1213379%	0,0910044%
12	13,35	16,5334	0,456	60000	0,6830741%	0,3415370%	0,1707574%	0,1138407%	0,0853815%
13	12,32	19,6521	0,456	60000	0,6487532%	0,3243766%	0,1621778%	0,1081208%	0,0810915%
14	11,44	23,7908	0,456	60000	0,6248697%	0,3124348%	0,1562073%	0,1041404%	0,0781062%
15	10,68	29,0049	0,456	60000	0,6096166%	0,3048083%	0,1523943%	0,1015984%	0,0761996%
16	10,01	35,4613	0,456	60000	0,6021682%	0,3010841%	0,1505323%	0,1003570%	0,0752686%
17	9,42	49,6331	0,456	60000	0,6300712%	0,3150356%	0,1575076%	0,1050073%	0,0787563%

Table 12. AFRAMAX - Percentage of the cost of turning circle manoeuvre on the total cost of voyage at cruise speed of 13 knots.

Speed Of Ap. (Knots)	Manoeuvring Time (Min)	Consumption (Kg/Min)	Fuel Cost (Usd/Kg)	Distance: 500 miles	Distance: 1000 miles	Distance: 2000 miles	Distance: 3000 miles	Distance: 4000 miles
				%	%	%	%	%
9	20,17	10,7705	0,4560	0,386717%	0,19335 8%	0,096679%	0,064453%	0,048340%
10	18,15	13,2409	0,4560	0,427875%	0,213938%	0,106969%	0,071313%	0,053484%
11	16,50	16,2700	0,4560	0,477964%	0,238982%	0,119491%	0,079661%	0,059745%
12	15,13	19,9407	0,4560	0,536981%	0,268491%	0,134245%	0,089497%	0,067123%
13	13,96	24,3361	0,4560	0,604933%	0,302467%	0,151233%	0,100822%	0,075617%
14	12,97	29,5389	0,4560	0,681814%	0,340907%	0,170454%	0,113636%	0,085227%
15	12,10	35,6323	0,4560	0,767631%	0,383815%	0,191908%	0,127938%	0,095954%
16	11,35	43,2751	0,4560	0,874013%	0,437007%	0,218503%	0,145669%	0,109252%
17	10,68	53,3600	0,4560	1,014301%	0,554248%	0,253575%	0,169050%	0,126788%

Table 13. SUEZMAX - Percentage of the consumption of turning circle manoeuvre on the total consumption of voyage at cruise speed of 13 knots.

Speed Of Ap. (Knots)	Manoeuvring Time (Min)	Consumption (Kg/Min)	Fuel Cost (Usd/Kg)	Hire (Usd)	Distance: 500 miles	Distance: 1000 miles	Distance: 2000 miles	Distance: 3000 miles	Distance: 4000 miles
					%	%	%	%	%
9	20,17	10,7705	0,456	18000	1,2174966%	0,6087483%	0,3043544%	0,2029073%	0,1521821%
10	18,15	13,2409	0,456	18000	1,1664482%	0,5832241%	0,2915931%	0,1943996%	0,1458013%
11	16,50	16,2700	0,456	18000	1,1394192%	0,5697096%	0,2848363%	0,1898950%	0,1424228%
12	15,13	19,9407	0,456	18000	1,1326104%	0,5663052%	0,2831342%	0,1887602%	0,1415717%
13	13,96	24,3361	0,456	18000	1,1420273%	0,5710136%	0,2854883%	0,1903296%	0,1427488%
14	12,97	29,5389	0,456	18000	1,1677154%	0,5838577%	0,2919099%	0,1946108%	0,1459597%
15	12,10	35,6323	0,456	18000	1,2059448%	0,6029724%	0,3014666%	0,2009821%	0,1507382%
16	11,35	43,2751	0,456	18000	1,2683294%	0,6341647%	0,3170617%	0,2113791%	0,1585360%
17	10,68	53,3600	0,456	18000	1,3637284%	0,6818642%	0,3409100%	0,2272782%	0,1704605%

Table 14. SUEZMAX - percentage of the cost of turning circle manoeuvre on the total cost of voyage at cruise speed of 13 knots.

Speed Of Ap. (Knots)	Manoeuvring Time (Min)	Consumption (Kg/Min)	Fuel Cost (Usd/Kg)	Hire (Usd)	Distance: 500 miles	Distance: 1000 miles	Distance: 2000 miles	Distance: 3000 miles	Distance: 4000 miles
					%	%	%	%	%
9	20,17	10,7705	0,456	60000	0,9770968%	0,4885484%	0,2442583%	0,1628424%	0,1221331%
10	18,15	13,2409	0,456	60000	0,9005065%	0,4502532%	0,2251120%	0,1500779%	0,1125597%
11	16,50	16,2700	0,456	60000	0,8423458%	0,4211729%	0,2105728%	0,1403849%	0,1052898%
12	15,13	19,9407	0,456	60000	0,7987448%	0,3993724%	0,1996732%	0,1331184%	0,0998399%
13	13,96	24,3361	0,456	60000	0,7660785%	0,3830392%	0,1915072%	0,1276742%	0,0957567%
14	12,97	29,5389	0,456	60000	0,7437537%	0,3718768%	0,1859263%	0,1239536%	0,0929662%
15	12,10	35,6323	0,456	60000	0,7288315%	0,3644157%	0,1821960%	0,1214666%	0,0911010%
16	11,35	43,2751	0,456	60000	0,7247959%	0,3623980%	0,1811872%	0,1207941%	0,0905965%
17	10,68	53,3600	0,456	60000	0,7330915%	0,3665457%	0,1832610%	0,1221766%	0,0916335%

Table 15. SUEZMAX- Percentage of the cost of turning circle manoeuvre on the total cost of voyage at cruise speed of 13 knots.

CONCLUSIONS

— The results for low velocities of approach obtained by interpolation should be considered incorrect and they are shown in this research only for reference purposes.

— The economic speed of the ship for the whole sea passage is close to the velocity of approach to track the more economic manoeuvre of turning 360 deg.

— The optimum speed to perform the manoeuvre of turning 360 deg will depend mainly on the petrol price and hire just as the results shown in table 16.

Table 16.

Hire (USD)	18000			30000			40000			60000		
F.O. price (USD)	0,3	0,5	0,6	0,3	0,5	0,6	0,3	0,5	0,6	0,3	0,5	0,6
SUEZMAX	13	12	10	15	13	11	16	14	12	max.	16	13
AFRAMAX	14	13	11	16	14	12	16	15	13	16	16	14

— The results should not be negligible with regard to the percentage of petrol consumed and costs during the manoeuvre of turn 360 deg out of the whole sea passage. In case of 500 miles sea passages, this percentage would be over one per cent in all cases assumed except one.
— The manoeuvre of turn 360 deg would be reconsidered for the SUEZMAX and AFRAMAX bearing in mind the following reasons:
  – Taking into account the urgency to carry out this manoeuvre by the Officer on watch, it may be unrealistic to reduce the power of main engine to reach the optimum speed of approach.
  – According to the results obtained, the cost of this manoeuvre is high compared to the whole sea passage.
  – Stopping the main engine may be more economic than turning 360 deg however the possibilities of keeping clear the other vessel are not so large. Extending this research to the manoeuvre of stopping the main engine may contribute with further conclusions.
— The research may also be extended to the determination of the costs during the periods of previous deceleration and subsequent acceleration to the turning circle manoeuvre.

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