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The Implication of the Stochastic Gross-profit-per-day Objective on the Cargo Ship Profitability, Capacity, and Speed

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ABSTRACT

Ship owners are used to maximizing a deterministic gross-profit objective. This objective may yield a grosser profit if the ship average fixed cost is minimized, which is achieved by building ships of larger capacities. As a result, the ship voyage time tends to prolong due to more cargo handling operations, longer distance due to route restriction, lightening of loads before canals, transshipment operations, and a slower ship speed. Latest research papers recommend a voyage stochastic gross-profit-per-day objective to be used instead. This new objective cares not only for the more voyage gross profit the ship is expected to earn but also for the fewer number of days the ship is expected to take to earn this gross profit. The objective permits the ship owner to earn more gross profit at the year end. And, because the shipping management is not always sure whether the same magnitude of gross profit can be maintained in the future of such ship voyages, that is why the maximization of the gross-profit-per-day objective needs to have a stochastic formulation based on a stochastic cargo transport demand. This paper studies the implication of the new objective on the ship profitability and the ship capacity and speed.

1. Introduction.

This paper opens the discussion about applying the concept of the stochastic gross-profit-per-day objective to all systems which have a time-variable operational cycle (El Noshokaty, 2018a), or systems which can employ different mixes of factors of production (El Noshokaty, 2018b). The former systems are by definition requiring different times for each operational cycle while the latter systems require different times for each mix of factors of production. Either type of systems may be found in single, decoupled, and coupled entities.

Examples are found in all means of cargo transport, oil and gas reservoir development, car assembly lines in the industry, cooperative farming and crop harvesting in agriculture, port cargo handling in trade, and road paving in construction. Applying the concept of the stochastic gross-profit-per-day objective is claimed by El Noshokaty (2017b) to influence the profitability and investments worth trillions of dollars in these systems.

According to the rate concept of the operational management, the time-variable operational cycle should maintain a maximum possible rate of output and should target a maximum possible gross profit per the operational cycle time. Unfortunately, this concept is not always followed where the operational management in some cases is still targeting the maximum possible amount of output and the maximum possible gross profit, regardless of how long the operational cycle might take to complete. These cases may be found more in businesses where future customer demand is poor and unknown. In such a situation, the operational management prefers to produce and sell now the maximum quantity the operational system can afford. The situation becomes worse when the customer demand does not amen to any forecasting pattern. When this situation persists, targeting the maximum possible gross profit becomes a normal practice. Among other industries, the shipping industry is experiencing such a situation. What is wondering is that Operations Research can resolve most of these situations. It can build a stochastic model based on the stochastic customer demand. The model objective is to maximize the gross profit-per-cycle-time subject to the constraints put on the operational

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capacity and the customer demand. Even in situations where the stochastic customer demand can't be anticipated, sensitivity and what-if analysis can introduce different scenarios based on the future customer demand.

In shipping, the rate concept implies the fact that the ship voyage is variable in time, the case which occurs when the ship is following the tramp mode of operation, or, when the ship capacity and speed are strategically subject to change either in the tramp or liner mode of operation. El Noshokaty, 2017a, and El Noshokaty, 2017b have developed the mathematical models to optimize a stochastic gross profit-per-day objective for the time-variable ship voyage. It also applies sensitivity and what-if analysis if there are any possible changes that might happen to cargo quantity and freight, cargo handling rate and charges, and ship speed and fuel consumption. The same analysis is used when the stochastic cargo transport demand can't be anticipated.

The above-mentioned research papers of El Noshokaty demonstrate the case where it is a worse situation for the profitability if the rate concept is not followed. Regretfully, management of the cargo ship transport operations is used to maximize a voyage gross-profit objective, assuming a deterministic cargo transport demand. What is worse for the profitability is that the management has started to apply what is called in Economics the economies of scale. According to this concept, the gross profit objective is assumed to yield a grosser profit if the ship average fixed cost is minimized, which may be achieved by building ships of larger capacities. As a result, the voyage time of the ship tends to prolong because of a more cargo handling operations of large loads, longer distance due to route restriction or more port calls, possible lightening of loads before passing canals, possible transshipment operations, and a most likely slower ship speed. The voyage time should not extend too long otherwise the gross profit-per-day will decrease and the larger capacity and the slower speed will then act against profitability. If the larger capacity from the rate concept perspective is tending to be less profitable in carrying large loads, it will definitely be costly enough in carrying small loads due to excessive port and canal dues. To prevent all this from happening, this paper is to study the implication on the ship profitability and design factors; namely the ship capacity and speed, when maximization of the stochastic gross-profit-per-day objective is considered. The paper introduces the mathematical model and the solution methodology used in the study. A case study is given to demonstrate the possible magnitude of the implication for the tramp shipping.

The following section brings about a review of the literature on the possible effects on the ship profitability, capacity, and speed, and whether there is any research work on the possible effects caused by the gross profit-per-day objective. The one next introduces the mathematical model and the solution methodology used to study the implication of the gross profit-per-day objective on the ship profitability, capacity, and speed. The following section demonstrates a case study in tramp shipping to find out if there is such implication and to size its magnitude, if any. The last section gives a concluding statement of the paper.

2. Review of the Literature.

To review the possible effects of the gross profit and the gross profit-per-day objectives on the ship profitability, the reader is requested to refer to El Noshokaty, 2013 and El Noshokaty, 2017b for liner shipping and El Noshokaty, 2014; El Noshokaty, 2017a; El Noshokaty, 2017b; and El Noshokaty, 2018c for tramp shipping. The former papers recommend the optimization of a stochastic gross profit objective while the latter papers recommend the optimization of a stochastic gross profit-per-day objective, rather than a deterministic gross profit one. Both groups of references also recommend the use of sensitivity and what-if analysis if the stochastic cargo transport demand can't be anticipated. As for the possible effects on the ship capacity and speed, there are only several research papers in the engineering design optimization. Examples are given by Papanikolaou, 2009; Michalski, 2016; and Szelangiewicz and Zelazny, 2016.

No research papers were found which study the implication of the gross profit-per-day objective on the ship profitability, capacity, and speed, combined. This includes both liner and tramp shipping. The reader may wonder why the paper studies the implication of the gross profit-per-day objective for liner shipping, where the ship voyage is not variable in time. The answer is that it does use the gross profit-per-day objective when the ship capacity and speed are subject to change the way which causes the liner voyage time to change as well.

3. The Mathematical Model and the Solution Methodology.

The mathematical model and the state-of-the-art solution methodology are exclusively developed by S. El Noshokaty. The model and the methodology used for liner shipping are included in El Noshokaty, 2013; El Noshokaty, 2017b; and SOS, 2018. SOS is a suite of decision support systems developed to support the ship owner optimizing the cargo mix selection of each ship (SOS Voyager), the trade areas allocated to each ship (SOS Allocator), and the appraisal of new ships (SOS Appraiser). SOS is here applied to a set of liner ships of different classes of capacities and speeds and to a set of designs of the same shipping line. Each design is tailored to suit each class of ships and a certain cargo transport demand, and describing the line ports and the port arrival dates. The ship which gives the maximum gross profit-per-day is proposed to work on the shipping line.

Likewise, the mathematical model and the solution methodology used for the tramp shipping are included in El Noshokaty, 2014; El Noshokaty, 2017a; El Noshokaty, 2017b; and SOS, 2018. SOS is here applied to a set of tramp ships of different classes of capacities and speeds and to a certain cargo transport demand available in a certain trade area. Cargo pick-up dates and other shipping elements and rules are assigned to all cargoes. The ships which give the maximum total gross profit-per-day are proposed to work on this trade area.

The ship-speed sensitivity and what-if analysis discussed in the above-mentioned references can be used here to study whether or not increasing the ship speed will improve the profitability.

4. A Case Study in Tramp Shipping.

This case demonstrates the situation where using a gross-profit-per-day objective with stochastic transport demand is considerably more profitable than using a gross profit objective with deterministic transport demand. It also demonstrates that the former objective favors the ships of lesser capacities and more speeds. It applies the model and methodology included in SOS, 2018. A shipping company is planning to charter-in one oil tanker as to compete in carrying part of the cargo transport demand. Tanker I, Tanker II, and Tanker III are three proposed types of oil tankers of different capacities and speeds. In the last quarter of the year 2018, these tanker types can compete in carrying ten crude oil cargoes. Three of these cargoes are to be transported from Kuwait to the USA, another three from Ukraine to China, and four from Venezuela to Latvia. Data on tankers, ports, and cargoes can be extracted and displayed using SOS, 2018. Relevant data on ships is shown in Table 1.

For Tanker type I and Tanker type III, their open port is Alexandria, Egypt. For Tanker type II, its open port is Odessa, Ukraine. For all tankers, the close port is the last port of call, where the open date is 1/10/2018 (dd/mm/yyyy is the date format), the close date is 31/12/2018, the voyage fixed cost is $1000, and the fixed time is 0.3 days. Relevant data on the port is shown in Table 2.

Ten crude oil cargoes represent the transport demand, of which eight cargoes have offered (confirmed) quantity and freight and two not-yet-offered cargoes (unconfirmed). Relevant data on cargoes is shown in Table 3.

where:

* All cargoes require heating, at ship owner's account. Crude Oil 1, 2, and 8 are transported directly (10,147 miles with 1.5 days waiting) or via Suez Canal (8,602 miles with 2 days waiting), Crude Oil 3 and 4 are transported directly (14,169 miles with 1 day waiting) or via Suez Canal (8,264 miles with 1 day waiting), and Crude Oil 5, 6, 7, and 10 are transported only directly (5,274 miles with 0.5 day waiting). Crude Oil 9 is transported directly (20,645 miles with 1.5 days waiting). Distance between ballast transport links may be found in any distance table (waiting days are assumed zero for these links).

** uc = unconfirmed quantity or freight. Freight is free in and out (FIO) base, load or discharge laydays are restricted to 35,000 mt per day, reversible laydays are subject to demurrage rate of US$ 8,000 per day, and dispatch rate of US$4,000 per day.

For the two unconfirmed cargoes, the company anticipates probabilities for five classes of quantity and freight for each cargo. The company also stipulates, by a least probability, to be able to transport a quantity of each cargo within its transport demand. Additional data of unconfirmed cargo is shown in Table 4. The company needs to know what type of tanker is most profitable. As the company is considering the use of a gross profit-per-day objective when selecting the optimal (best) cargo mix, it needs to know whether this new objective influences the tanker-type selection expressed in tanker capacity and speed, compared to the old gross profit objective. Also, it needs to know whether considering the unconfirmed cargoes has an additional impact on the selection of the tanker type.

In the beginning, SOS Voyager optimization model is used to find the optimal (best) cargo mix for each tanker type, where data in Table 4 is turned to deterministic-equivalent quantities as shown in Table 5 (see SOS, 2018 for details).

Applying the stochastic gross profit-per-day objective to the tanker types gives the result reported in Table 6. The table displays the cargo mix, route, and the stochastic gross-profit-per-day classified by tanker type and speed level.

Suppose now that the stochastic profit-per-day criterion is discarded and the stochastic gross profit criterion is used instead (which can be handled also by SOS Voyager). Table 7 displays the results of this case, assuming all the tanker types are at low speed. Table 7 is broken down into the voyage details displayed in Table 8.

Suppose now that the unconfirmed cargoes: 'Crude Oil 8' and 'Crude Oil 10' are discarded, the stochastic gross profit criterion is also discarded, and the gross profit criterion is used instead. Table 9 displays the results of this case, assuming all the taker types are at low speed. Table 9 is broken down into the voyage details displayed in Table 10. The following is some analysis based on the findings displayed in Tables 6 to 10:

a) From the profitability perspective, Table 6 shows a stochastic gross profit-per-day for all tanker types at the low speed greater than that given by Table 8 ($76,687 for the former and $ 62,337 for the latter). Table 6 is produced by a model of stochastic gross profit-per-day objective, while Table 8 gives a stochastic gross profit-per-day equivalent to the stochastic gross profit shown in Table 7. Table 7 is produced by a model of a stochastic gross profit objective, where the gross profit is not in proportion to voyage time. Tables 6 to 8 consider some stochastic cargo transport demand. Likewise, Table 6 shows a stochastic gross profit-per-day for all tanker types at the low speed greater than that given by Table 10 ($76,687 for the former and $ 53,724 for the latter). Table 10 gives a gross profit-per-day equivalent to the gross profit shown in Table 9. Table 9 is produced by a model of a gross profit objective, where the gross profit is not in proportion to voyage time and no stochastic cargo transport demand is considered.

b) From the ship design perspective, namely: the ship capacity and speed, Table 6 shows an inefficient use of the larger capacity and the slower speed. Tanker type III of 170,000 dwt is carrying Crude Oil 2 and 8 totaling 111,000 tons ignoring Crude Oil 9 of 170,000 tons because it causes inefficient utilization of the tanker, time-wise, though it brings grosser profit. It cuts a long distance from Odessa in Ukraine to Shanghai in China via Cape of Good Hope. Whereas Table 7 shows full utilization of the larger capacity even at slower speed, where Tanker type III picks Crude Oil 9 apart from how long it takes the ship to reach Shanghai. Careful analysis of Table 6 shows an increase in the stochastic gross profit-per-day for all tanker types of about 25% due to the increase in tanker speed from an average 14 miles/hour to an average 16, while the increase is about 10% due to the increase in tanker speed from an average 16 miles/hour to an average 18. Another useful observation is that the decrease in the stochastic gross profit-per-

Table 1: Ship data.

Data item* Ship	Tanker type I	Tanker type II	Tanker type III
-Deadweight in mt	40,000	50,000	170,000
-Low, medium, and high speed in miles/hour	15; 17; 19	14; 16; 18	13; 15; 17
-Main engine laden fuel consumption in mt/day, each speed level	16; 19; 24	14; 18; 22	13; 16; 20
-Main engine ballast fuel consumption in mt/day, each speed level	10; 13; 20	9; 12; 18	8; 11; 16
-Auxiliary engine fuel consumption in mt/day	1	1	1
-Heating fuel consumption mt of main engine fuel/day/100 mt of cargo	0.125	0.11	0.1
-Sues Canal dues, laden and ballast in US$	158,960; 135,180	172,310; 146,560	413,303; 351,680
-Panama Canal dues, laden and ballast in US$	79,000; 62,900	98,250; 78,150	502,500; 398,400
-Bosporus and Dardanelles dues in US$	9,640	12,150	21,673
-Running cost in US$/day	5,000	7,000	7,700

where:
mt = metric ton.
Fuel cost for main engine is 450 US$/mt.
Fuel cost for auxiliary engine is 675 US$/mt.
Source: Authors.

Table 2: Port data.

Data item Port name	Cost/call in US$ (Lights, towage)	Cost/day in US$ (Quay services)	Waiting days (Anchor, idle)*	Cargo handling mt/day
Alexandria (Egypt)	1,500	150	0	34,000
Baltimore	12,000	1,200	0.3	40,000
Shuaiba (Kuwait)	8,000	800	0.5	37,000
Maracaibo	10,700	1,070	0.5	37,000
Odessa	10,000	1,000	0.5	35,000
Riga (Latvia)	11,000	1,100	0.3	35,000
Shanghai	9,000	900	0.4	35,000

where:
* Port waiting days are classified as ‘force majeure’ and hence are not part of any demurrage or dispatch time counts.
Source: Authors.

Table 3: Cargo data.

Data item Cargo*	Shipping event	Load port	Load Laycan	Discharge port	Discharge Laycan	Weight in mt**	Freight In US$/mt**
Crude Oil 1	Offered	Shuaiba	1-10/10	Baltimore	1-10/11	40,000	50
Crude Oil 2	Offered	Shuaiba	20-27/10	Baltimore	20-27/11	60,000	60
Crude Oil 3	Offered	Odessa	5-15/10	Shanghai	5-15/11	35,000	40
Crude Oil 4	Offered	Odessa	3-16/11	Shanghai	3-16/12	40,000	50
Crude Oil 5	Offered	Maracaibo	5-15/12	Riga	20-30/12	30,000	30
Crude Oil 6	Offered	Maracaibo	20-30/11	Riga	10-25/12	45,000	35
Crude Oil 7	Offered	Maracaibo	1-10/12	Riga	20-30/12	40,000	40
Crude Oil 8	Not-yet-offered	Shuaiba	1-31/10	Baltimore	1-30/11	uc	uc
Crude Oil 9	Offered	Odessa	1-30/10	Shanghai	1-31/12	170,000	60
Crude Oil 10	Not-yet-offered	Maracaibo	1-30/11	Riga	1-30/11	uc	uc

where:
* All cargoes require heating, at ship owner's account. Crude Oil 1, 2, and 8 are transported directly (10,147 miles with 1.5 days waiting) or via Suez Canal (8,602 miles with 2 days waiting), Crude Oil 3 and 4 are transported directly (14,169 miles with 1 day waiting) or via Suez Canal (8,264 miles with 1 day waiting), and Crude Oil 5, 6, 7, and 10 are transported only directly (5,274 miles with 0.5 day waiting). Crude Oil 9 is transported directly (20,645 miles with 1.5 days waiting). Distance between ballast transport links may be found in any distance table (waiting days are assumed zero for these links).
** uc = unconfirmed quantity or freight. Freight is free in and out (FIO) base, load or discharge laydays are restricted to 35,000 mt per day, reversible laydays are subject to demurrage rate of US$ 8,000 per day, and dispatch rate of US$4,000 per day.

Source: Authors.

Table 4: Unconfirmed cargo additional data.

Data item Cargo	Crude Oil 8	Crude Oil 10
Class 1		
Weight in mt	45,000	30,000
Freight in US$/mt	50	35
Probability in %	5	5
Class 2		
Weight in mt	47,000	32,000
Freight in US$/mt	50	35
Probability in %	15	15
Class 3		
Weight in mt	49,000	34,000
Freight in US$/mt	50	35
Probability in %	50	60
Class 4		
Weight in mt	51,000	36,000
Freight in US$/mt	50	35
Probability in %	20	15
Class 5		
Weight in mt	53,000	38,000
Freight in US$/mt	50	35
Probability in %	10	5

Source: Authors.

Table 5: Unconfirmed cargo deterministic-equivalent quantity and freight.

Data item Cargo	Crude Oil 8	Crude Oil 10
Weight in mt	51,000	36,000
Freight in US$/mt	50	35
Least probability of transporting cargo quantity in %	70	40

Source: Authors.

Table 6: Cargo mix, route, and stochastic gross-profit-per-day classified by ship and speed level.

Data item Speed level/Ship	Tanker type I	Tanker type II	Tanker type III	Total stochastic gross profit per day in US$
Cargo mix Low Route	Crude oil 7 and 10 Maracibo-Riga	Crude Oil 6 Maracibo- Riga	Crude oil 2, and 8 Shuaiba-Baltimore (directly)	76, 687
Cargo mix Medium Route	Crude oil 1 Shuaiba-Baltimore (directly)	Crude oil 7 and 10 Maracibo-Riga	Crude oil 2, and 8 Shuaiba-Baltimore (directly)	96,102
Cargo mix High Route	Crude oil 1 Shuaiba-Baltimore (directly)	Crude oil 7 and 10 Maracibo- Riga	Crude oil 2, and 8 Shuaiba-Baltimore (directly)	105,620
Total stochastic gross profit per day in US$	56,365	34,125	187,738	

Source: Authors.

Table 7: Cargo mix, route, and stochastic gross profit of each ship at low speed.

Data item Ship	Tanker type I	Tanker type II	Tanker type III	Stochastic gross profit in US$
Cargo mix	Crude oil 7 and 10	Crude Oil 6	Crude oil 9	
Route	Maracibo-Riga	Maracibo- Riga	Odessa-Shanghai (directly)	5,076,546

Source: Authors.

Table 8: Voyage details reported for each ship at low speed.

Ship Voyage details	Tanker type I	Tanker type II	Tanker type III	Total
Stochastic gross profit ($)	1,271,156	405,833	3,399,291	**5,076,280**
Days	82.6	71.9	82.3	-
Stochastic gross profit/day ($)	15,389	5,644	41,304	**62,337**

Source: Authors.

Table 9: Cargo mix, route, and gross profit of each ship at low speed.

Data item Ship	Tanker type I	Tanker type II	Tanker type III	Gross profit in US$
Cargo mix	Crude oil 7	Crude Oil 6	Crude oil 9	**4,358,639**
Route	Maracibo-Riga	Maracibo- Riga	Odessa-Shanghai (directly)	

Source: Authors.

Table 10: Voyage details reported for each ship at low speed.

Ship Voyage details	Tanker type I	Tanker type II	Tanker type III	Total
Stochastic gross profit ($)	553,586	405,833	3,399,291	**4,358,710**
Days	81.7	71.9	82.3	-
Stochastic gross profit/day ($)	6,776	5,644	41,304	**53,724**

Source: Authors.

day for all ship speeds is about 40% due the chartering-in of Tanker type II compared to Tanker type I, while the increase is about 233% due the chartering-in of Tanker type III compared to Tanker type I. For the cargo transport demand shown in Tables 3 to 5, the above-mentioned analysis suggests the chartering-in of tanker of Type III of an average capacity of no more than 120,000 tons and an average speed around 16 miles/hour.

c) More insights into the overall tables reveal two key management concepts behind the better profitability and the optimal ship capacity and speed. They are the production ratio and the demand forecast. The former concept cares for both the gross profit and the production time the way which leads to a maximum gross profit at the end of the year. The latter concept works in synchronization with the former. It looks ahead in the future to guarantee that the ratio concept will not work against a better profitability by picking a future poor demand on the account of the current rich one, if any.

Concluding Statement.

This paper takes the lead in revising the current practices of the management of the cargo ship transport operations. The management is used to maximizing a voyage gross-profit objective, assuming a deterministic cargo transport demand. According to the economies of scale, this objective yields a grosser profit if the ship average fixed cost is minimized, which may be achieved by building ships of larger capacities. As a result, the voyage time of the ship tends to prolong due to more cargo handling operations of large loads, longer distance due to route restriction or more port calls, possible lightening of loads before passing canals, possible transshipment operations, and most likely a slower ship speed. Latest research papers recommend a voyage stochastic gross-profit-per-day objective to be used instead, assuming both deterministic and stochastic cargo transport demand. This new objective cares not only for the more voyage gross profit the ship is expected to earn but also for the fewer number of days the ship is expected to take to earn this gross profit. The voyage gross-profit-per-day objective permits the ship owner to maximize the yearly gross profit by repeating an expected higher voyage gross profit more number of times the year around. And, because the shipping management is not always sure whether the same magnitude of gross profit can be maintained in the future of such ship voyages, that is why the maximization of the gross-profit-per-day objective needs to have a stochastic formulation based on a stochastic cargo transport demand.

This paper studies the implication on the ship profitability and design factors; namely the ship capacity and speed, when maximization of the stochastic gross-profit-per-day objective is considered. The paper introduces the mathematical model and the solution methodology used in the study. A case study is given to demonstrate the possible magnitude of the implication. The case concluded that if the management of the ship operations follows the production ratio and the cargo demand forecast concepts it can improve the profitability of the shipping company and be able to select the proper capacities and speeds for the ships the company employs. This conclusion is not only useful for the shipping or other cargo transport companies but also for businesses like gas reservoir development, car assembly lines in the industry, cooperative farming and crop harvesting in agriculture, port cargo handling in trade, and road paving in construction.

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