Int j simul model 18 (2019) 4, 596-607
ISSN 1726-4529 Preliminary scientific communication

SHIPS SHORE SERVICE OPTIMIZATION USING THE QUEUEING THEORY

Bebic, D.*; Stazic, L.** & Komar, I.**
* Gearbulk Norway AS, N-5160 Laksevag, Bergen, Norway
** University of Split, Faculty of Maritime Studies, R. Boskovica 37, Split, Croatia
E-Mail: dragan.bebic@gearbulk.com, lstazic@pfst.hr, ikomar@pfst.hr

Abstract
This paper is presenting a solution for simplifying shore maintenance service teams scheduling procedure in the maritime industry. Shore maintenance service teams scheduling procedure in the past required either advanced mathematical knowledge in the area of the queueing theory or adequate computerized software for the calculation. That action in the past was usually outsourced; companies did not have personnel capable of solving the queueing theory nor the software needed for the calculation. The solution, presented in the paper, enables in-house scheduling of the shore maintenance service teams using only basic knowledge of the theory, without the use of the specially designed software. The scheduling is performed using a simplified Excel template for Queueing theory, inserting the data from ship's Computerized Planned Maintenance System. The Excel template, after filling the data, determines the optimal number of teams for the fleet and performs the calculation according to the desired or optimal service level. Simplified Excel template for Queueing theory cut the costs for the calculation and scheduling enabling additional savings in the industry.
(Received in June 2019, accepted in October 2019. This paper was with the authors 3 weeks for 1 revision.)

Key Words: Queueing Process, Arrival Rate, Service Time, Service Team, System Utilization, Maintenance, Costs

1. INTRODUCTION

Maritime shipping business is highly dependable on numerous global factors (Fig. 1) and therefore subjected to constant changes in the business model and adjustments according to the industry benchmarking of the OPEX (Vessel daily OPerating EXpenses). The competition on today's shipping market is vast [1], like in all other industries (*"the manufacturing industry is currently under strong pressure to swiftly and easily adapt to changes"* [2]), especially when considering that supply and demand are not in balance for an extended period of time. Therefore, shipping companies are facing a constant challenge to run a profitable business. In that respect the most common way to remain profitable and win the contract before the competition is cutting the OPEX. However, most of the budget accounts in the OPEX are already at the minimum, and further cutting would endanger the safety of the vessels. During the time, some of the maritime companies observed that budget for the crew costs represent great part of the OPEX expenses [3], and considerable savings can be achieved by hiring less expensive crew (according to research performed by authors, yearly savings can accumulate up to $130.000 per vessel, which is significant part of the Bulk Carrier OPEX). Most of the shipping companies are following this path. The side effect of the less expensive crew is visible in the poorer maintenance and increase of damage cases and unplanned maintenance, mostly rectified on high cost by shore services. This happens because less expensive crew is, in general, less skilled too. In most companies, this consequence was calculated, and as long as the damage cases price tag is lower than savings on the crew expenses, the risk is acceptable. To prevent malfunctions which can be created by less skilled crew, companies are turning towards shore-based service for the maintenance of the vital equipment. The idea of shore service maintenance for the vital equipment and the machinery

https://doi.org/10.2507/IJSIMM18(4)488

is not new. Certain companies are using this kind of support, modified according their preferences.

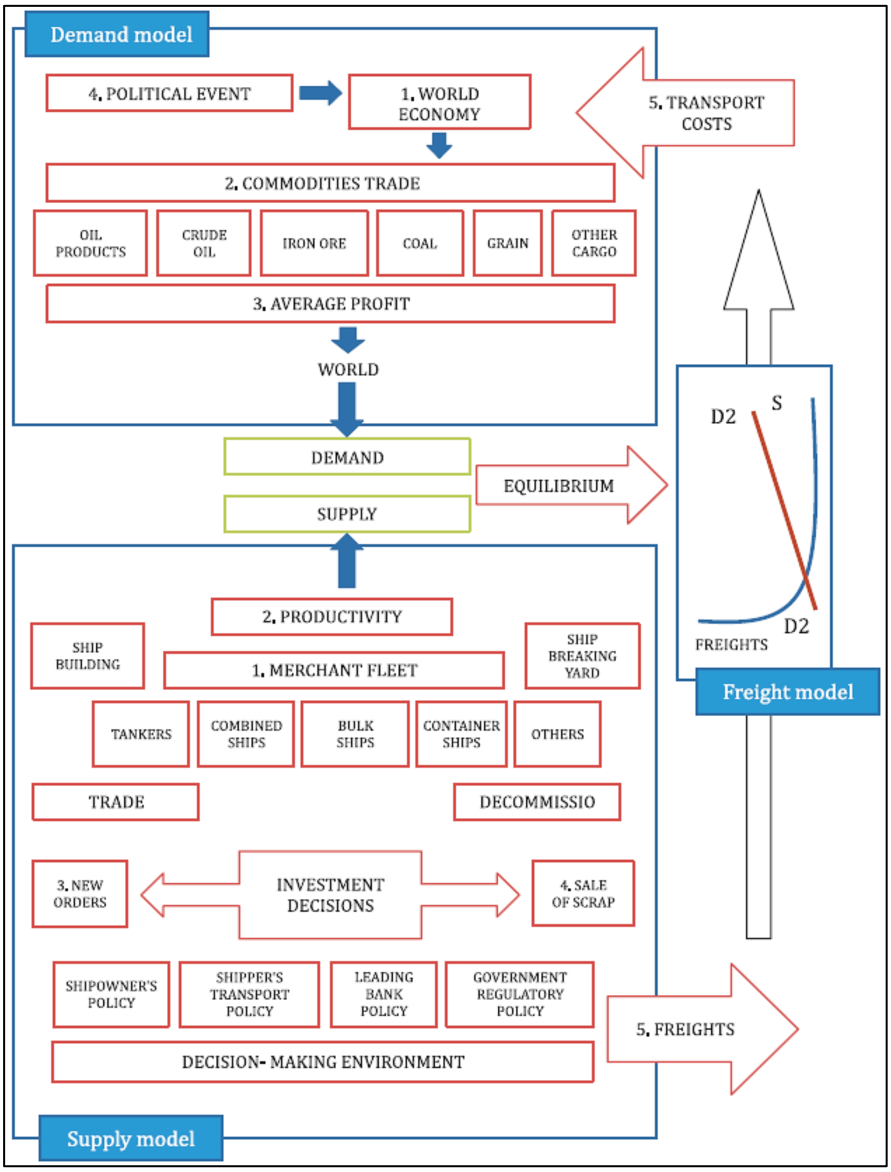

Figure 1: The shipping market model [4, 5].

Example of a modification is servicing of diesel aggregates which could be either entirely overhauled by shore service or they can have ready on the stock reconditioned spare parts for on-board delivery when the engine is due for an overhaul. The crew needs to replace these components on the engine and send back replaced parts for reconditioning. Shore service maintenance tends to increase in intensity in the future, not just because on-board crews are becoming less skilled, but as consequence of the development of autonomous ships. The cost for this kind of service arrangement is in the range of $15,000 - $35,000 per engine, depending of the type and size of the engine.

To decrease the costs of the service arrangement, shipping companies are creating in-house service teams, often created with specialized intentions. These teams should consist of experienced engineers and mechanics familiar with this kind of job (preferably ex-crewmembers of the same company). Proper scheduling of such teams is *"an important function that determines the efficiency and productivity"* [6] and requires quite advanced knowledge of the queuing theory or some computerized program as an aid. Usually, that knowledge is not available in the conservative shipping industry environment [7] and companies have to hire consultants to perform the action or to buy software designed for the action. Both actions require additional costs which will diminish potential savings of the whole arrangement.

Queuing and scheduling problems are known for a long time [8], especially in the land transport sector, with a several solutions proposed for the problem [9-11]. In the manufacturing and industry sector, optimization, queuing and scheduling is also addressed by multitude of different solutions for problems [12, 13]. Most of the mentioned solutions are applicable in the maritime and shipping industry, but actual usage is limited due to price and attitude of the human factor.

This paper analyses usage of the simplified Excel template for Queueing theory as a problem-solving solution for organizing schedule for in-house service teams for diesel generator overhaul, an example created only for comparison purposes. Use of this template should solve the problem of the scheduling of the shore maintenance service teams using only basic knowledge of the theory, without the use of the specially designed software, therefore cutting the expenses needed for the software or the consultancy.

Real fleet of 45 vessels has been analysed in this example, together with the actual data, all in order to facilitate a proper base for realistic calculation. Queueing theory [14, 15] is used for this type of the calculation.

2. QUEUEING THEORY APPROACH FOR CASE ANALYSIS

The queuing theory is one of the methods of operational research that studies the problems of queuing, whose content is the serving of randomly received units or requests for a service [16]. In the analysed case, due to a specific approach, the classic structure of the queueing system (customer arrival – waiting for service – servers – leaving the system) is changed. The change is visible in the fact that all the elements still exist, but the service teams are coming to the vessel (customer), not the other way around.

Queueing theory is quite complicated [17], requires advanced mathematical knowledge and therefore has not been used widely for practical problem solving. Team at the Alberta University created a highly useful Queueing “tool pack 4.0” application for Excel [18] as a tool for solving queuing and scheduling problems. The app is easy to use, although it is still required the basic knowledge of Queueing theory for setting up the problem.

The base for the calculation is the data of all generator engines on 45 vessels. The data is collected usually from ship’s computerized PMS – Planned Maintenance System (such as Amos, Bassnet, Sertica or similar) where all necessary data (*TBO* – time between overhaul; average daily running hours, date of overhauls) is available. This data enables calculation of next due overhaul dates, if not calculated by PMS.

Table I: Diesel generator data for fleet of 45 vessels.

Item no.	Vessel code – Eng. no	*TBO* as per instr. Manual	Average daily *RH*	First overhaul	Second overhaul	Third overhaul
1	Vsl_A_Eng_1	20,000	12.20	24/09/2008	21/03/2013	15/09/2017
2	Vsl_A_Eng_2	20,000	11.30	29/03/2009	31/01/2014	06/12/2018
3	Vsl_A_Eng_3	20,000	11.50	01/10/2007	05/07/2012	09/04/2017
132	Vsl_AS_Eng_1	16,000	11.43	05/09/2009	05/07/2013	05/05/2017
133	Vsl_AS_Eng_2	16,000	8.42	09/01/2011	23/03/2016	05/06/2021
134	Vsl_AS_Eng_3	16,000	10.12	01/03/2010	29/06/2014	27/10/2018

Table II: Time between vessels arrival into Queueing system.

Vessel code – Eng. no.	**Date of planned overhaul**	**Time between vessel's arrival (days)**
Vsl_C_Eng_1	02/10/2006	1
Vsl_W_Eng_1	13/10/2006	11
Vsl_I_Eng_2	07/11/2006	25
Vsl_AL_Eng_1	09/11/2018	11
Vsl_A_Eng_2	06/12/2018	27
Vsl_AR_Eng_3	31/12/2018	25
Total number of units in interval (2006-2018)		378
Total number of days in interval (2006-2018)		4474
Average number of units per day		0.08449

Data in Table II is sorted in ascending order and shows an overview of time between vessels arrival (due date for engine overhaul). Table III represents the summary of the characteristics of the queueing process, used in the final calculation.

Table III: Queueing process summary from the Table II.

Characteristics of Queueing Process		
Average time interval between two units (days)	t_{arr}	11.83858
Arrival rate (per day)	λ	0.8449
Service rate (per day)	μ	0.10345

Arrival rate λ was calculated from the data in the Table II using Eq. (1):

$$\lambda = \frac{Total\ number\ of\ units\ in\ interval\ (2006-2018)}{Total\ number\ of\ days\ in\ interval\ (2006-2018)} \tag{1}$$

Service rate μ was calculated by Eq. (2):

$$\mu = (Average\ value\ of\ options\ 1, 2\ \&3)^{-1} \tag{2}$$

where:

- Engine overhaul completed during one port stay. Total of six days.
- The vessel’s port stay is less than six days, so the service team stays onboard for crossing short distance to the next port. Service team spent nine days onboard.
- The vessel’s port stay is less than six days, so the service team stays onboard for crossing long distance to the next port. Service team spent 14 days onboard.

It is already given that use of the particular queueing model depends on the specific system to be analysed. Queueing models [19] are identified with combination of letters separated with symbol ‘’/’’. For this analysis model M/M/s/∞/FIFO will be used.

The meaning of M/M/s/∞/FIFO model is:

- M – stands for Markovian process. By this process, arrival or service rate follows a Poisson distribution, while the exponential distribution describes the time between arrivals or service time.
- s – stands for the number of servers.
- ∞ - refers to infinite system capacity.
- FIFO – refers to queue discipline (First in – first out).

3. CONFIRMATION OF A MARKOVIAN PROCESS

To confirm the first condition of a Markovian process (time between arrivals follows exponential distribution), Table IV derives from data for all fleet.

Table IV: Annual mean time between vessels arrival.

Year	Mean time (days)	λ
2007	11	0.09239
2008	9	0.11732
2009	8	0.11953
2010	11	0.08849
2011	10	0.10099
2012	11	0.08761
2013	11	0.08824
2014	11	0.09284
2015	11	0.08742
2016	18	0.05567
2017	21	0.04861
2018	27	0.03762
Average	**13**	**0.08473**

Data in the Table V is calculated by exponential distribution – Eq. (3) [20]:

$$f(x) = \lambda e^{-\lambda x} \tag{3}$$

Table V: Density in time interval for randomly chosen functions from Table IV.

Interval	Density function λ=0.11953	Density function λ=0.05567	Density function λ=0.08473
0	0.1195	0.0557	0.0847
1	0.1061	0.0527	0.0778
2	0.0941	0.0498	0.0715
62	0.0001	0.0018	0.0004
63	0.0001	0.0017	0.0004
64	0.0001	0.0016	0.0004

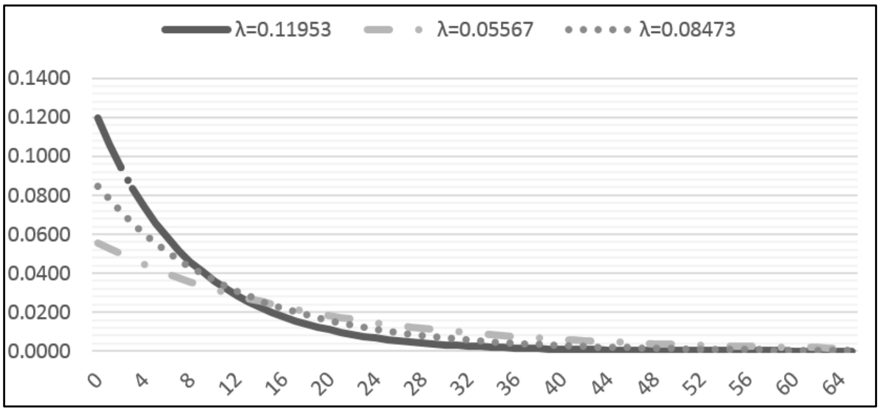

Figure 2: Time between vessels arrival (exponential distribution).

Distribution of vessels arrival rate (the second condition of a Markovian process) is calculated by Eq. (4) [21]:

$$P(k) = \frac{\lambda^k \cdot e^{-\lambda}}{k!} \tag{4}$$

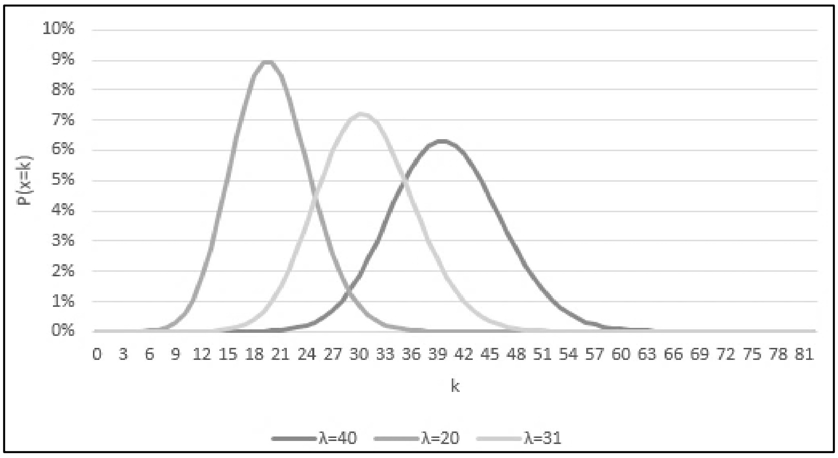

Figure 3: Vessels arrival rate (Poisson distribution).

According to the results shown in Figs. 2 and 3, a Markovian process is confirmed for the analysed case.

4. CALCULATION

The template [18] will perform the final calculation after entering the following data:

- Arrival rate 0.08449, received from Table III,
- Service rate 0.10345, received from Table III,
- Desired service level,
- Threshold time (It is period of time, given in days, needed to complete the service. This time can be inserted from user's experience, maker's maintenance handbook or some data handbook [22].),
- Number of service personnel (service teams).

Desired service level (90 %) and **threshold time** (15 days) are set considering pre-designed use of diesel aggregates on board cargo vessels. The majority of the cargo vessels have three units, two of them are more than enough to fulfil all requirements of the ship, either at sea or in port under cargo operation. The third unit is redundancy and therefore operability of the vessel itself is not in question if expected time in queue increases a couple of days. Besides, observing from the point of the ship-owner, increase the desired service level over the specific limit, might request additional service team, and consequently, additional cost.

Number of service personnel (service teams) is a variable which should be changed during the calculation. Usually, the calculation starts with one service team (cheapest solution), value should be increased until desired service level and threshold time are obtained.

Fig. 4 presents the results of one of the basic performance measures (and quick preview) of the system efficiency, for one service team. That is the probability of the number of ships in the service process per number of units in a queue. For example, if ten vessels are in the system at the same time (which is the case in analysed company), probability that vessel will not be in a queue is only 2.4 %, telling that the system with one service team is not efficient at all.

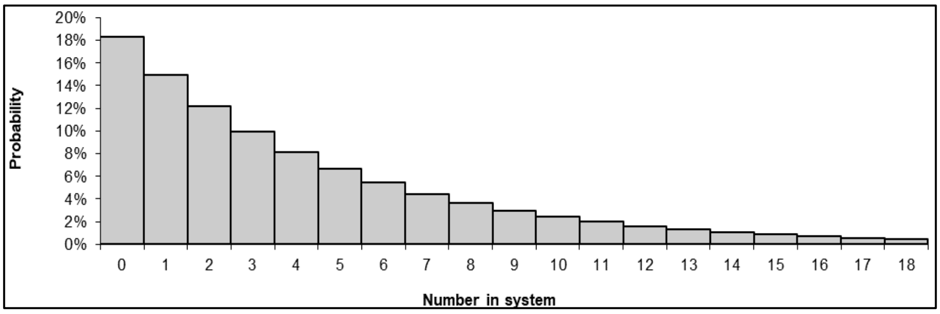

Figure 4: Probability for number of vessels in system, based on calculation for one service team.

The Template shown in Fig. 5 presents data calculated for one service team.

M/M/s Queueing Calculations						
	Basic Parameters					
λ	Arrival Rate	0.08449	per day	Number in system	Number in queue	Probability
μ	Service Rate	0.10345	per day	**0**	**0**	**18%**
S	Number of Teams	1		**1**	**0**	**15%**
t	Time Unit	day		**2**	**1**	**12%**
				3	**2**	**10%**
	Basic Performance Measures			**4**	**3**	**8%**
ρ_s	Utilization	**82%**		**5**	**4**	**7%**
P(0)	Probability that the system is empty	**18%**		**6**	**5**	**5%**
Lq	Expected number in queue	**3.6395**		**7**	**6**	**4%**
Lq	L, expected number in system	**4.4562**		**8**	**7**	**4%**
Wq	Expected time in queue	**43.0761**		**9**	**8**	**3%**
W	Expected total time in system	**52.7426**		**10**	**9**	**2%**
P(n)	Probability that customer waits	**82%**		**11**	**10**	**2%**
				12	**11**	**2%**
	Advanced Parameters			**13**	**12**	**1%**
	Threshold time	15	days	**14**	**13**	**1%**
	Desired service level	90%		**15**	**14**	**1%**
				16	**15**	**1%**
	Advanced Performance Measures			**17**	**16**	**1%**
	Current service level	**39%**		**18**	**17**	**0%**
	Number of Teams required to achieve desired service level	**2**		**19**	**18**	**0%**
				20	**19**	**0%**
				Total		**99%**

Figure 5: Queueing calculation for one service team [18].

It is visible that obtained results for one service team are not optimal. The current service level for one team is only 39 %, far from the desired service level of 90 %. It means that only 39 % of the vessels will be serviced in the desired threshold time of 15 days. The remaining 61 % of the ships will have to wait for the service. Besides, 'Basic Performance Measures' is showing that the expected total time in the system is too long, almost 53 days. As calculation for one service team is not satisfactory, calculation for two service teams should be performed.

Fig. 6 presents the calculation results for two teams.

Similar to the probability graph in Fig. 4, the graph in Fig. 7 presents the probability of the total number of vessels in the system for two service teams. A quick comparison of these two graphs illustrates the point of the advantage of the system with two service teams. For example, only four vessels are expected with the probability of 2.4 % in the graph in Fig. 7, while expectancy in Fig. 4 is ten ships for the same likelihood. Comparison of Figs. 4 and 7 shows that less number of the ships presented in the graph for the corresponding expectation is in direct relation to the efficiency of the system.

M/M/s Queueing Calculations						
Basic Parameters						
λ	Arrival Rate	0.08449	per day	Number in system	Number in queue	Probability
μ	Service Rate	0.10345	per day	0	0	42%
S	Number of Teams	2		1	0	34%
t	Time Unit	day		2	0	14%
				3	1	6%
Basic Performance Measures				4	2	2%
ρs	Utilization	41%		5	3	1%
P(0)	Probability that the system is empty	42%		6	4	0%
Lq	Expected number in queue	0.1635		7	5	0%
Lq	L, expected number in system	0.9802		8	6	0%
Wq	Expected time in queue	1.9346		9	7	0%
W	Expected total time in system	11.6011		10	8	0%
P(n)	Probability that customer waits	24%		11	9	0%
				12	10	0%
Advanced Parameters				13	11	0%
	Threshold time	15	days	14	12	0%
	Desired service level	90%		15	13	0%
				16	14	0%
Advanced Performance Measures				17	15	0%
	Current service level	96%		18	16	0%
	Number of Teams required to					
	achieve desired service level	2		19	17	0%
				20	18	0%
				Total		100%

Figure 6: Queueing calculation for two service teams [18].

The output results significantly differ from the previous calculation. The current service level increases to 96 %, above the desired service level. The expected total time in the system drops from 53 days to 12 days and the expected time in the queue drops from 43 to 2 days.

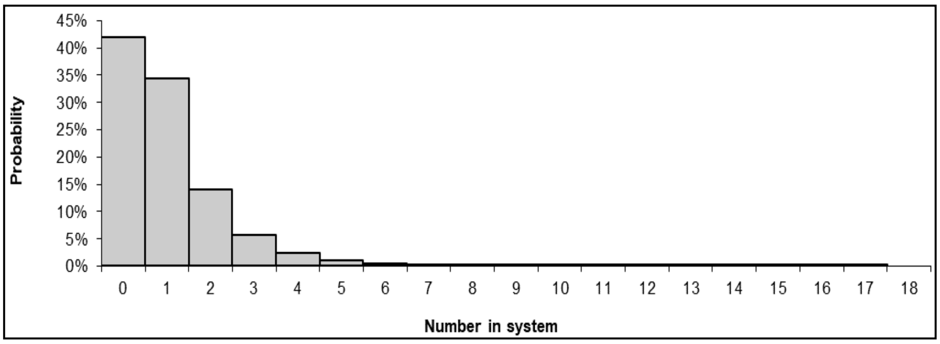

Figure 7: Probability for number of vessels in the system, based on calculation for two service teams.

Results obtained for two service teams fulfil all required conditions and the calculation should finish there, any further calculation does not have any economical or logical reason; that is confirmed with the calculation shown in Fig. 8.

Service utilization for three service teams dropped to only 27 %. Also, based on the template calculation, two service teams are optimum to achieve the desired service level (see at the bottom of Fig. 8).

According to the analysis, conclusion is that two service teams are sufficient to fulfil requirements for servicing 45 vessels within a threshold time of 15 days and at the desired service level of 90 %.

Increase of the desired service level to higher value of 95 % will yield exactly same results shown in Fig. 6, with current service level of 96 %. Further increase of the desired service level will lead to the situation presented in Fig. 8, to an extreme drop in system utilization as well as a considerable cost for the additional service team.

M/M/s Queueing Calculations						
Basic Parameters						
λ	Arrival Rate	0.08449	per day	Number in system	Number in queue	Probability
μ	Service Rate	0.10345	per day	0	0	44%
S	Number of Servers	3		1	0	36%
t	Time Unit	day		2	0	15%
				3	0	4%
Basic Performance Measures				4	1	1%
ρ_S	Utilization	27%		5	2	0%
P(0)	Probability that the system is empty	44%		6	3	0%
Lq	Expected number in queue	0.0205		7	4	0%
Lq	L, expected number in system	0.8372		8	5	0%
Wq	Expected time in queue	0.2428		9	6	0%
W	Expected total time in system	9.9093		10	7	0%
P(n)	Probability that customer waits	5%		11	8	0%
				12	9	0%
Advanced Parameters				13	10	0%
	Threshold time	15	days	14	11	0%
	Desired service level	90%		15	12	0%
				16	13	0%
Advanced Performance Measures				17	14	0%
	Current service level	100%		18	15	0%
	Number of servers required to achieve desired service level	2		19	16	0%
				20	17	0%
				Total		100%

Figure 8: Queueing calculation for three service teams [18].

5. PRACTICAL VALUE

This simplified Excel template for Queueing theory can be used in practice in every shipping company where can save a significant amount of money and time. Costs of the calculation of the queuing and scheduling vary from the arrangement, in general between $8,000 and $20,000, for every calculation.

The annual cost for service teams [23] is:

- Annual cost for two experienced engineers: $8,000 × 12 × 2 = $192,000,
- Annual cost for two experienced mechanics: $2,500 × 12 × 2 = $60,000,
- Total annual cost for two in-house service teams: $192,000 + $60,000 = $252,000.

The number of annual arrivals for service (λ in Table VI) affect service teams cost through the amount of traveling, as they are on the fixed yearly payment system. Based on annual average arrivals, the calculation for flight cost is:

- Annual cost for team travels: 64 × $500 = $32,000.

Based on the above calculation, the total annual cost for in-house teams, including annual travels, would be $284,000. If this sum is divided to 45 vessels, it will increase vessel budget for $6,311 per year.

The cost for shore service team is in the range of $15,000 to $35,000 for an intervention, based on whether specialized maker service team or independent small service companies are performing the job. The majority of the ship-owners for the job would prefer small service companies (which are cheaper for similar quality of service), providing they have a license for a particular engine. Therefore, the cost calculation for shore service team (Table VI) is based on a lower value of $15,000 per one service.

Table VI: Annual cost comparison.

Year	λ	In-house service team cost (incl. Travel cost)	Shore service team cost (incl. Travel cost)
2007	34	$286,000	$544,000
2008	43	$295,000	$688,000
2009	40	$292,000	$640,000
2010	35	$287,000	$560,000
2011	36	$288,000	$576,000
2012	32	$284,000	$512,000
2013	32	$284,000	$512,000
2014	35	$287,000	$560,000
2015	30	$282,000	$480,000
2016	20	$272,000	$320,000
2017	19	$271,000	$304,000
2018	14	$266,000	$224,000
Total cost:		**$3,394,000**	**$5,920,000**
Savings:		**$2,526,000**	

Fig. 9 presents comparison of data from Table VII. It is evident that maintaining in-house service teams is much economically sound option than hiring shore teams when service is required. The only exception is for the year 2018 when shore service cost is cheaper than in-house service team. However, this is due to extremely low arrival rate λ = 14 (half of the average arrival date).

Use of the simplified Excel template for Queueing theory, as shown in the paper, can save additionally 3.2 % (up to 7.9 %) of total savings which will be spent on the calculation of the queuing and scheduling.

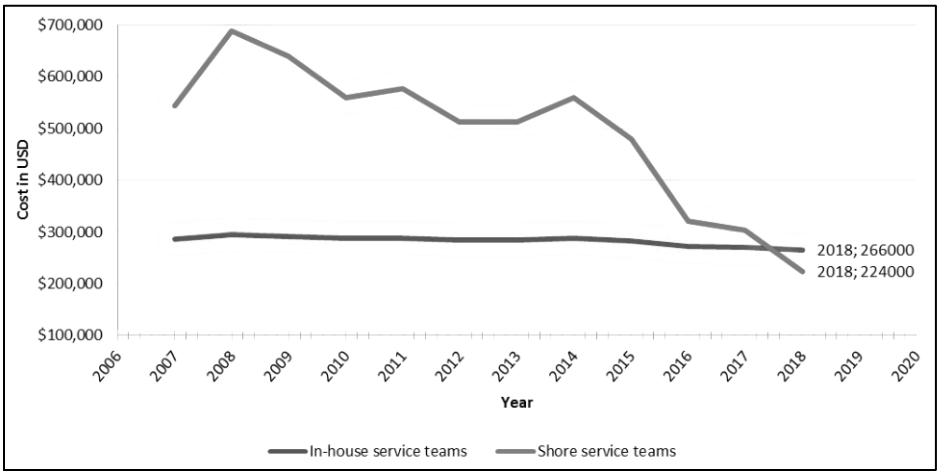

Figure 9: Cost comparison.

6. CONCLUSION

The demanding maritime market requires frequent reductions in operating costs. The creation of in-house service teams, which would perform overhauls of some important machinery, imposes itself as a necessity which will enable some savings. Creation of those teams raises the question of how to determine the optimal number of teams for each particular fleet and how to optimally organize the team's scheduling by ships in the fleet. In order to answer these two questions, advanced knowledge of the Queueing theory is needed, often not present among the employees in shipping companies.

Application of the simplified Excel template for Queueing theory, as shown in the paper, removed the need of advanced knowledge of the Queueing theory for the task. Calculation of the optimal number of in-house service teams is turned into something simple, into entering the data from company Planned Maintenance System into the template. This method has determined the optimal number of in-house service teams (two teams) for the analysed fleet, obtaining a service level of 96 %.

Potential creation of the in-house service teams and following scheduling performed with the simplified Excel template for Queueing theory for analysed example shows possible savings of more than $2,526,000 for the fleet.

In the highly competitive shipping market, the correct decision makes the differences as well as an advantage on the market. Presented model is intended to be clear, simple and easy to understand; an example how to cheaply solve the queuing and scheduling problem in the maritime industry. It will not yield the kind of savings which might significantly influence the company's business, but it is indeed the example of how use of the simple tool and proper analysis might deliver data for the correct decision. Besides, the efficiency of any company depends on the right decision made on each level, no matter how small saving it might result.

REFERENCES

[1] Kemene, A. (2018). Shipping Market Overview, Optima Shipping Services, China Ship and Finance Summit, from *https://www.marinemoney.com/system/files/media/2018-05/1%20Angelica%20Kemene.pdf*¸ accessed on 02-01-2019

[2] Vrecko, I.; Kovac, J.; Rupnik, B.; Gajsek, B. (2019). Using queuing simulation model in production process innovations, *International Journal of Simulation Modelling*, Vol. 18, No. 1, 47-58, doi:10.2507/IJSIMM18(1)458

[3] Chubb, N. (2018). Three ways to reduce your OpEx without compromising on performance, Intelligent Cargo Systems, from *https://www.intelligentcargosystems.com/three-ways-to-reduce-your-opex-without-compromising-on-performance*, accessed on 20-03-2019

[4] Stopford, M. (2009). *Maritime Economics*, 3rd edition, Supply, demand and freight rates (p. 116), Routledge / Taylor & Francis, London

[5] Jugović, A.; Komadina, N; Perić Hadžić, A. (2015). Factors influencing the formation of freight rates on maritime shipping markets, *Pomorstvo – Scientific Journal of Maritime Research*, Vol. 29, No. 1, 23-29

[6] Aydemir, E.; Koruca, H. I. (2015). A new production scheduling module using priority-rule based genetic algorithm, *International Journal of Simulation Modelling*, Vol. 14, No. 3, 450-462, doi:10.2507/IJSIMM14(3)7.299

[7] Manuel, M. E. (2012). *Maritime Risk and Organizational Learning*, Ashgate Publishing Ltd., Surrey

[8] Ceder, A. (1984). Bus frequency determination using passenger count data, *Transportation Research Part A: General*, Vol. 18, No. 5-6, 439-453, doi:10.1016/0191-2607(84)90019-0

[9] Hartmann Tolić, I.; Martinović, G.; Crnjac Milić, D. (2018). Optimization methods in modern transportation systems, *Technical Gazette*, Vol. 25, No. 2, 627-634, doi:10.17559/TV-20170326212717

[10] Niu, H.; Zhou, X.; Gao, R. (2015). Train scheduling for minimizing passenger waiting time with time-dependent demand and skip-stop patterns: Nonlinear integer programming models with linear constraints, *Transportation Research Part B: Methodological*, Vol. 76, 117-135, doi:10.1016/j.trb.2015.03.004

[11] Gkiotsalitis, K.; Alesiani, F. (2019). Robust timetable optimization for bus lines subject to resource and regulatory constraints, *Transportation Research Part E: Logistics and Transportation Review*, Vol. 128, 30-51, doi:10.1016/j.tre.2019.05.016

[12] Gingu (Boteanu), E. I.; Zapciu, M.; Cavalieri, S. (2017). Production systems flow modelling using decomposition method and required buffers, *International Journal of Simulation Modelling*, Vol. 16, No. 2, 207-218, doi:10.2507/IJSIMM16(2)2.367

[13] Gao, S.; Rubrico, J. I. U.; Higashi, T.; Kobayashi, T.; Taneda, K.; Ota, J. (2019). Efficient throughput analysis of production lines based on modular queues, *IEEE Access*, Vol. 7, 95314-95326, doi:10.1109/ACCESS.2019.2928309

[14] Sztrik, J. (2012). *Basic Queueing Theory*, University of Debrecen, Faculty of Informatics, Debrecen

[15] Zenzerović, Z. (2003). *Queueing Theory (Teorija redova čekanja)*, Maritime Faculty in Rijeka, Rijeka (in Croatian)

[16] Krpan, L.; Maršanić, R.; Milković, M. (2017). A model of the dimensioning of the number of service places at parking lot entrances by using the queuing theory, *Technical Gazette*, Vol. 24, No. 1, 231-238, doi:10.17559/TV-20160128161848

[17] Campello, F.; Ingolfsson, A.; Shumsky, R. A. (2017). Queueing models of case managers, *Management Science*, Vol. 63, No. 3, 587-900, doi:10.1287/mnsc.2015.2368

[18] Ingolfsson, A.; Gallop, F. (2013-14). Queueing ToolPak 4.0, Template for Waiting Line Analysis, from *http://queueingtoolpak.org/qtp40/distribution40/template.xls*, accessed on 25-09-2017

[19] Bhat, U. N. (2015). *An Introduction to Queueing Theory: Modeling and Analysis in Applications*, 2nd edition, Birkhäuser, Basel

[20] McCool, J. I. (2012). *Using the Weibull Distribution: Reliability, Modeling and Inference*, John Wiley & Sons, Inc., Hoboken

[21] Moore, D. S.; McCabe, G. P; Craig, B. A. (2017). *Introduction to the Practice of Statistics*, 9th edition, W. H. Freeman & Co., New York

[22] SINTEF Technology and Society, NTNU (2015). OREDA: Offshore and Onshore Reliability Data Handbook, 6th edition, Oreda Participants, Det Norske Veritas, Germanischer Lloyd

[23] PayScale, – Salary Comparison, Salary Survey, Search Wages, from *https://www.payscale.com/*, accessed on 22-02-2019