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A Fuzzy-Genetic Modelling Approach to Maintenance Scheduling for the Minimization of Fishing Vessel Idle Time in the Maritime Industry

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ABSTRACT

As the marine industry becomes more complex and challenging to manage optimizing the idle time of vessels is critical. Although previous idle time reduction efforts in maintenance were through the evaluation of crisp numerical values in optimization models, none of the studies has considered the effect of uncertainty and imprecision on the system. Consequently, in this paper, a linguistic-based optimization model is developed using the fuzzy-genetic model for the discredited time-maintenance manpower-cost saving problem. The suggested model is moved for the following reasons: (1) it considers linguistic terms to express the optimization of vessels' idle time from a unique perspective of deploying genetic algorithm while considering the minimum and maximum number of times vessels may return for maintenance (2) it has an indirect measure of the quality of maintenance service which is absent in previous models (3) a cost-saving dimension is introduced where the ideas of low, medium and high-cost savings are examined. The results show the feasibility of the approach. The model advanced promises to provide vessel controllers with an idle time assessment framework, which enhances the chances of generating the utmost profit for companies.

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1. INTRODUCTION

The literature relating to maintenance scheduling is wide and is still expanding (Alkhamis and Yellen, 1995; Anily *et al.*, 1998,1999; Charles-Owaba, 2002; Oke and Charles-Owaba, 2005a,c). However, the development and integration of soft computing tools into production systems are also well understood in the literature (Chanas and Kasperski, 2001; Foretemps, 1997; Itoh and Ishii, 1999; Fayad and Petrovic, 2005,

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Petrovic and Fayad, 2004; Petrovic and Geiger, 2004; Walker *et al*., 2001). Application has also been made to services (Li and Kwan, 2001), and is gradually extending to maintenance scheduling (Oke and Charles-Owaba, 2005b; Abdulwhab *et al*., 2004; El-Sharkh *et al*., 2003; El-Sharkh and El-Kerb, 2003). However, a promising area of research in scheduling relates to the development of hybrid models (Ram and Olumolade, 1987), and fuzzy and genetic systems (Sakawa and Kubota, 2000; El-Sharkh *et al*., 2003). However, the works by El-Sharkh *et al*. (2003) and El-Sharkh and El-Kerb (2003) form the foundation for the current paper and have directed its thrust.

Nonetheless, in commercial fishing literature, several aspects of the research have been conducted. Examples are as follows. Sandsund et al. (2019) established musculoskeletal symptoms among people in commercial fishing in Norway. It was concluded that musculoskeletal issues are prevalent among commercial fishers. But roughly 77% of fishers in vessels studied declared good and very good health status. From the preceding article, it is understandable that musculoskeletal issues may result in sickness absence and hospitalization. Hence, Oren et al. (2019) followed up the previous research by Sandsund et al. (2019) by analyzing the prevalence of doctor-attested sick leave among Norwegian fishers. In conclusion, the authors confirmed that musculoskeletal issues are top-rated causal factors of sick leave attestation by doctors in Norway.

The above literature review has dealt with the health and ergonomic issues of the commercial fishing business and its association with fishing vessels. However, another aspect of interest is the investigation related to the profit of the catch business for fishing vessel organizations. In this aspect, Vassdal and Bertheussen (2020) analyzed the profit estimates of a fishing vessel organization. It was concluded that the catch business unit perspective utilized in the article is effective. Closely related to the previous article is the study on the profitability of fishing vessels by Bertheussen and Vassdal (2021) which empirically analyzed Norwegian seagoing workers. They concluded that substantial profitability enhancements are linked to established institutions and their activities. Moreover, the focus of Aprilliani et al. (2020) is to examine the proportion of the principal dimensions of a vessel in its relative performance with multipurpose gear. It was concluded that the length/breadth proportion seems to exceed the minimum criteria. Furthermore, Burella et al. (2019) provided a framework to analyze the strategies for the maintenance of fishing vessels when risk is factored into the analysis. The suggested model is a mechanism to estimate maintenance interval time for main propulsion systems and risk factors are established by goal definitions. It was concluded that 45% savings in the cost of maintenance budgets was achieved.

Interestingly, to run a profitable organization, one of the factors planners consider is the percentage of hours a machine or piece of equipment is run in a predetermined period. It would be very desirable if production equipment could be run continuously for its whole lifetime but preventive maintenance is a must for all equipment if they are to give their best service for their design lifetimes. Hence, the challenge is to schedule maintenance periods such that they provide the minimum disruption possible to productive work by this equipment. This paper aims to present an alternative way of modeling the maintenance-scheduling problem and then to give figures derived from simulations. Optimization is carried out by the use of genetic algorithms. This involves the generation of initial solutions that match the objective function's definition and constraints and then further improving them by using natural mutating and crossover techniques. The final results are then chosen as the final solution to the problem.

This paper considers a hypothetical fishing company with trawlers that have to report in for maintenance according to a planned schedule. Since a planned schedule is being considered, maintenance activities due to eventualities such as hurricane damage are not considered. The paper seeks to minimize the idle time of such vessels. The idle time under consideration is the time the vessels spend not doing productive work. This includes the time that vessels spend returning to the docks for maintenance and the time they spend in the docks waiting for maintenance to start. It can easily be seen that the minimum time is non-zero. Specific trawlers are taken and subject to defined constraints, the minimum time spent by these trawlers is found using optimization techniques based on genetic algorithms.

The maintenance system in place is such that there are standard maintenance crews. Depending on the estimated amount of work to be done on the vessel, crews are assigned to the vessels. The availability of crews is subjective as it can be influenced by factors ranging from weather conditions to the total number of docked vessels in other dockyards. The subjectivity of this parameter is taken care of with the use of a fuzzy set to represent the available number of crews. The time is discretized by dividing it into units (preferably weeks) and each ship will come in for its maintenance within a time slot. It is desirable for the number of returns a vessel makes in a planning period to be bounded for proper evaluation of its productivity. A vessel that returns a minimum number of times while hauling in large tonnages would be seen to be a very productive vessel. It is also taken that there is a limitation on the number of vessels that can be in the maintenance facility at a time for reasons of space and maintenance equipment.

The remaining parts of this paper are sectioned into model development, fuzzy components and membership, case study, and conclusion. Model development has two aspects: notations, and model formulation. The notations used in the body of this paper are first defined, and then the analytical framework for the model is presented. The next section discusses the fuzzy component of the model. It is at this stage that the subjectivity of parameters would be treated. A case illustration is then made on a fishing company vessel maintenance system with an illustrative computer program adapted to solve the problem.

2. MODEL DEVELOPMENT

2.1 Definition of parameters and notations

The following represents the parameters and notations used in the work.

t : discretized period index
T : set of all periods i.e. the planning period
T_m : a set of maintenance time indices ($T_m \subset T$)
γ : maintenance period index ($\gamma \in T_m$)
i : vessel index
I : a set of all vessel indices i.e. the fleet
K : number of vessels in the fleet ($N(I) = k,\ i \in I$)
I_m : a set of vessels I in maintenance ($I_m \subset I$)
ρ : index of vessels I in maintenance ($\rho \in I_m$)
AM_t : available manpower at period t
c : a crew of maintenance workmen
n : integers representing the number of available maintenance crews
RMC_{it}^{min} : minimum number of crew required for the maintenance of vessel i for period t
r_i^{min} : minimum number of times vessel i may return for maintenance during the planning period
r_i^{max} : maximum number of times vessel i may return for maintenance during the planning period
r_i : number of times vessel i returned for maintenance in the planning period
TM_{it} : the time required for maintenance of i in period t.
TO_{it} : a time i operates in period t.
y_{it} : maintenance start indicator

LC : low-cost savings
MC : medium cost savings
HC : high-cost savings

Discretized time index: A value sequence that matches specific instantaneous time. It is similar to a continuous function and maps the various inputs, including time spent in maintenance, quantity, quality, and cost of materials used for maintenance, materials availability, and vessel life while the output is the quantity of service rendered to the vessels. A perspective of visualizing this problem is to assume a non-zero integer T_mE the discrete-time in a manner that t.e discrete time, $x(t + T_m) = x(t)$. Here, the smallest known value of T_m may be defined as the primary period. *Planning period*: Time ranges that are used for energy planning data. Within this period the anticipated quality service of vessels for a given scenario plan is predicted. It is often evaluated from a reference period to a future period. *Maintenance time indices*: These are maintenance indicators used to control the planning activities for the maintenance system. In a way, they evaluate any of the following according to the set goal of the maintenance manager: reactive maintenance hours, work order cycle period, maintenance cost, unscheduled downtime, and mean time between failures. In this work, the aspect described extends to the gamma function described in the list of notations, which is described as a subset of Tm. *Set of all vessels*: A group of trawler vessels sailing together, owned by the organization being analyzed, for the same set of activities. *The crew of maintenance workmen*: This is a group of workers responsible for fixing and maintaining the trawler vessels. They also engage in the routine maintenance of the trawler vessels. *The minimum number of crew required*: To operate a trawler vessel, the need number of crew is a function of many things: How urgently the repair service is needed, the capacity of the vessel (high capacity engines may require an assistant or assistants for physical or mental contribution to the maintenance activity. Notwithstanding, technology nowadays is reducing the manual labor required for vessel repairs as many of the components are automated. Besides, the replacement of components of vessels and sub-parts is becoming common in the day-to-day maintenance activities of trawler vessels. It is important to know that the presence of the maintenance crew keeps the vessel operating smoothly. *Low medium and high-cost savings*: In maintaining trawler vessels, substantial costs are expended by way of part replacements, engagement of ad-hoc staff, consultants for special services, and other activities. However, through training and demonstration of special skills by a new or old maintenance worker, certainly, anticipated expenditures may not be embarked upon again. In this instance, the organization avoids the expenditures. It could be the brilliance of the crew to have improvised (developed local substitutes for) components, which ordinarily would have been ordered from overseas using the hard-earned money of the company to purchase for foreign exchange. Apart from the cost of the components, hours of production lost are a cost to the organization. Thus, low, medium, and high-cost savings refer to the advantages that the vessel organization derives from the local substitution initiatives of the maintenance crew, for the parts, which could have been imported from overseas. These actions minimize the vessel organization's total expenditure while conserving the profit. Notice that this spending influences the bottom line of the vessel organization. It is also found out that apart from local substitution of parts, the maintenance manager and his/her crew may engage in improving the efficiency of the trawler vessel and also negotiate reduced prices of supplies to the company, an action that could result in low, medium or high-cost savings for the organization.

2.2 Model formulation

The problem statement is as follows:
"Minimize the difference between the time a vessel spends being maintained, and the time it spends doing productive work, and the total period under consideration."

In other words, it could be stated as:
Minimize [Total period under consideration – (time a vessel spends being maintained + the time it spends doing productive work)]

The motivation for this is to minimize avoidable delays. However, effective control of minimizing idle time could be achieved if a penalty cost, usually referred to as the opportunity cost of being idle could be charged. Such a factor could be incorporated into the model developed on fuzzy-genetic concepts. However, future studies could consider this. It is thus avoided here for simplification of model development. Mathematically, for a total planning period, T, operating periods, $TO_{it,}$ and maintenance periods TM_{it}, the problem statement above can be generally written as:

$$\text{Minimize}\,[T - \left(\text{sum of } \left(TO_{it}\right)\right)\Big) + \text{sum of } \left(TM_{it}\right) \forall\ t \in T \qquad (1)$$

This is an initial formulation. The expression is modified accordingly. The maintenance start indicator is defined as follows:

$$y_{it} = \begin{cases} 1, & e_i < t < l_i - TM_{it} \quad \forall \\ 0, & \text{otherwise} \end{cases} \qquad (2)$$

$e_i < t < l_i - TM_{it}$ represents the maintenance start periods. Using the maintenance start indicator, equation (1) is modified as follows:

$$\text{a.sum of } (TO_{it}) = \sum_{i \in I} \sum_{t \in T} \left(TO_{it} * \left(1 - y_{it}\right)\right) \qquad (3)$$

$$\text{b. sum of } (TM_{it}) = \sum_{\rho \in I_m} \sum_{\gamma \in T_m} \left(TM_{\rho\gamma} * y_{\rho\gamma}\right) \qquad (4)$$

since during maintenance $t = \gamma$, $T = T_m$, $i = \rho$ and $I = I_m$

Putting (3) and (4) in (1), we obtain:

$$\min(\sum (T - (\sum_{i \in T} \sum_{t \in T} \left(TO_{it} * \left(1 - y_{it}\right)\right) + \sum_{\rho \in Im y \in Tm} \sum \left(TM_{py} * \left(1 - y_{py}\right)\right)))) \qquad (5)$$

Equation (5) represents the objective function of the optimization problem. The constraints of the function are determined as follows:

$$\text{a. } y_{it} = \begin{cases} 1, e_i < t < l_1 - TM_{it} \ \forall\ t \\ 0, \qquad \text{otherwise} \end{cases}$$

b. The number of times a vessel I returns for preventive maintenance in a planning period is bounded. Mathematically,

$$r_i^{max} \le r_i \le r_i^{max} \qquad (6)$$

c. The available manpower should not be less than the required minimum number of crews for the maintenance of vessel i for period t, i.e.

$$\sum_{\rho \in Im} \sum_{\gamma \in Im} RMC_{\rho y}^{min} \le \sum_{t \in T} AM_t \qquad (7)$$

The available manpower can be expressed in terms of the number of crews

$$\sum_{t \in T} AM_t = nc \qquad (8)$$

$$\sum_{\rho \in Im} \sum_{\gamma \in Im} RMC_{\rho y}^{min} \le nc \qquad (9)$$

d. The total time spent in maintenance for any vessel i should not be greater than the total time the vessel spends in operation doing productive work i.e.

$$\sum_{i \in I} \sum_{t \in T} TO_{it} > \sum_{\rho \in Im} \sum_{\gamma \in Tm} TM_{\rho\gamma} \qquad (10)$$

The fuzzy-genetic system for the maintenance scheduling process first establishes the fuzzy logic controller, which receives material availability, vessel life, and maintenance period as inputs while the output is the quality of maintenance service (Fig. 1).

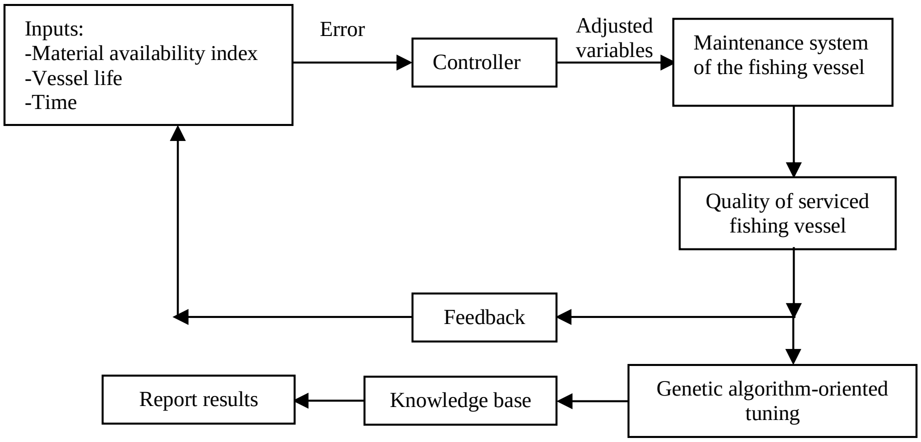

Fig. 1. A fuzzy-genetic system for the maintenance scheduling process

As the vessels are serviced, they are regarded to be in an as-good-as-new state such that they do not break down immediately they are used only for a limited time for operations before being returned for maintenance again. However, notice that the quality service expected from the maintenance service only appears after the application of the genetic algorithm-oriented turning while the fuzzy system had been done first.

A knowledge base framework assists in generating discriminant features (i.e. combined features of the maintenance data with attributes that separate the various inputs and outputs to the maintenance system. Through the knowledge base, a complicated set of mappings is done between the various inputs (such as the material availability, duration of maintenance, and vessel life) and the output (quality and maintenance service rendered to the fishing vessel). As such, the genetic algorithm, which terminates the fuzzy-genetic method used in this study, obtains near-optimal solutions as in the case of the difficult maintenance scheduling problem considered in the present study.

The issue is that the solution of the maintenance scheduling problem, which would have taken an unreasonable time to resolve, will now be resolved on time through the activity of the genetic algorithm. Then the results are reported. To emphasize the fuzzy controller system, the inputs are first served for errors, which are noise that competes with the signals to lower the quality of service. Then a controller acts on the inputs that transform the variables. The variables are then fed into the maintenance system. The fuzzy system brings out an output with which the response to the signal is determined. Finally, the sensor or translator acts on the information from the responses while the output is sent to the genetic algorithm.

In this article, several parameters have been considered during the model development. However, some additional parameters that might affect idle time need consideration. Material availability for maintenance (docking) is a key parameter. It is found that prices of maintenance spares influence the cost of shipping vessel service. Due to surges in the prices of spares and the inability of the vessel company to obtain foreign exchange for purchase, the spares may not be ready as the repair time will be delayed. A second parameter is the vessel life. For example, the old vessel may need extra time for the repair process. This is because as the major repair is done, there could be some minor repairs, which will be done to avoid the vessel being sent back for maintenance soon after being released for operations. From the above, material availability and vessel life are important parameters that might affect the idle time of vessels. Notwithstanding, for the simplicity of the model and avoiding the difficulty of sourcing data it is downplayed in the modelling efforts. However, future studies need to consider these parameters for more robust model development.

3. Fuzzy components and membership functions

The most subjective of all the parameters (constraints) listed above is the availability of maintenance crews. Their availability may be influenced by many factors. Thus, if the total number of crews available ranges from (n – a) to (n + b) where n, a and b are integers, then the membership function for the fuzzy set of available crews μac can be defined as follows (Fig. 2).

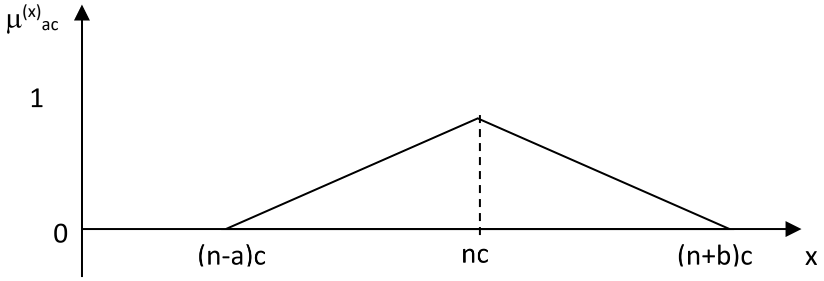

Fig. 2. Membership functions for the total number of crew available in the range

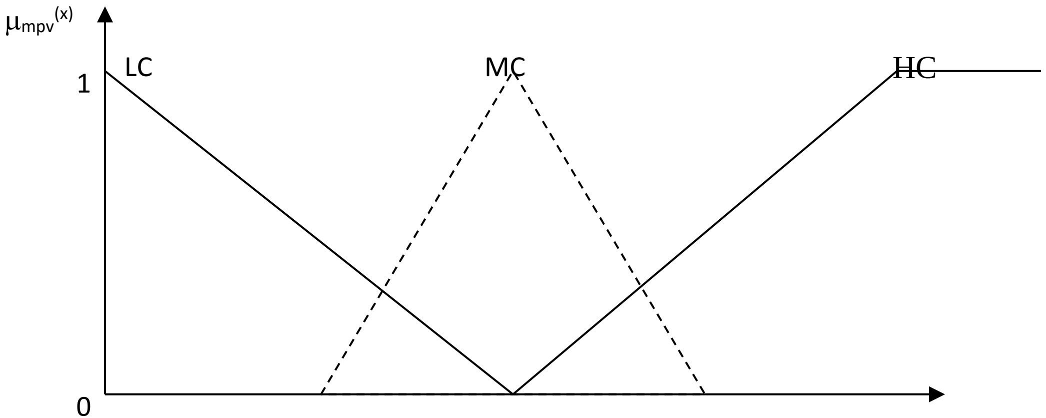

Fig. 3. Membership function for the manpower violation

μ_{ac} can be defined analytically as:

$$\mu_{ac} = \begin{cases} 0, & 0 < x \leq)n - a)c \\ \dfrac{x - (n - a)c}{c} & (n - a)c < x \leq nc \\ \dfrac{(n + b)c - x}{bc} & nc < c \leq (n + b)c \\ 0, & x > (n + b)c \end{cases} \quad (11)$$

In some cases, it may be desirable for the maintenance firm to employ less than the required number of crews if the cost savings from such practice is high compared to the idle time resulting from such practices. For that case, the manpower violation, α_{mpv} can be defined

as: $\alpha_{mpv} = \sum_{\rho \in \mathrm{Im}} \sum_{\gamma \in Tm} \mathrm{RMC}_{\rho\gamma} - \sum_{t \in T} \mathrm{AM}_t$ (12)

or using (9):

$$\alpha_{\mathrm{mpv}} = \sum_{\rho\in \mathrm{Im}} \sum_{\gamma\in Tm} \mathrm{RMC}_{\rho\gamma} - \mathrm{nc} \qquad (13)$$

The graphical representation of the membership function for the manpower violation α_{mpv}, μ_{mpv} is shown in Figure 3.

4. CASE STUDY

To verify the application of the model, data relating to the fishing organization considered is used. Software called GOAL 2.0 for genetic algorithm programming, obtained from the Internet was used to run the program that generated results. The genetic algorithm used here has eight parameters of concern, namely: A population of 30 units, A generation is 100, The reproduction type is 2 point crossover, The selection type is tournament selection, Elitism is 1, The mutation probability is 0.005, The reproduction probability is 0.85, and The simulation was run 10 times. A typical example of the evolution data set is shown in Table 2. This is the result for the first run while summaries of the results for all runs are shown in Table 1.

Table 1. The optimal solution for all runs

Run	DL	dm	di	dov	Objective Function
1	23.1305	2.9961	2.9955	11.9977	-5.1413
2	23.1369	2.9973	2.9953	11.9938	-5.1505
3	23.0256	2.9634	2.9931	11.9836	-5.0856
4	23.0008	2.9955	2.9959	11.9845	-5.0250
5	23.1305	2.9961	2.9955	11.9977	-5.1416
6	23.0006	2.9437	2.9909	11.9841	-5.0767
7	23.1371	2.9945	2.8370	11.9882	-5.3174
8	23.0337	2.8388	2.9944	11.9998	-5.2007
9	23.1344	2.9434	2.9977	11.9970	-5.1963
10	23.0012	2.8355	2.9436	11.9845	-5.2375

Table 2. The results generated for the genetic algorithm analysis

Generation	No. Valid Solutions	Mean	Std Deviation	Mutations	Reproductions	Optimum genotype	Optimum genotype	Optimum
0	30	-7.905	0.8472666	23	11	1E+128	23.0778512; 2.71804; 2.9683584; 11.5860704;	5.8053824
1	20	-5.0571	1.7438427	11	13	1E+128	23.0712976; 2.71804; -2.9683642; 11.5860704;	5.798823
2	20	-4.8055	1.657084	16	14	1E+128	23.0712976; 2.71804; 2.9683642; 11.5860704;	5.798823
3	22	-5.2588	1.4507053	23	14	1E+128	23.0712976; 2.71804; 2.9683642; 11.5860704;	5.798823
4	19	-4.1438	1.5718023	24	13	1E+126	23.9700032; 2.7991622; 2.03551599298982E-39; 11.1483704;	5.7802202
5	21	-4.3925	1.3631943	15	13	1E+126	23.1353408; 2.605527; 2.9691912; 10.7996384;	5.7764234
6	23	-4.7921	1.1567239	23	14	1.01E+128	1539655.7029376; 2.3562054; 2.954871; 11.5860592;	5.745568
7	20	-4.1122	1.4179917	25	15	1E+125	23.3450624; 2.5514606; 2.9683642; 11.5860704;	5.5719898
8	18	-3.7256	1.5416092	18	12	1E+128	23.1368336; 2.7628102; 2.9692944; 11.8327392;	5.5719898
9	15	-3.1224	1.6150438	21	15	1E+128	23.1368336; 2.7628102; 2.9692944; 11.8327392;	5.5719898
10	16	-3.5706	1.7237203	17	13	1.1E+128	23.1364656; 2.553095; 2.796463; 11.8303544;	5.5719898
11	12	-2.5108	1.5584245	15	13	1E+128	23.1368336; 2.3759686; 1.892595; 11.590584;	5.5719898
12	13	-2.6894	1.5765544	16	13	1E+128	23.1368336; 2.7628102; 2.9692944; 11.8327392;	5.5719898
…	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
90	12	-2.5014	1.5525726	15	11	1E+128	23.0029968; 2.8381972; 2.9940752; 11.9439952;	5.2267292
91	13	-2.7623	1.6192606	26	14	1E+128	23.0029968; 2.8381974; 2.9940752; 11.9407184;	5.2267292
92	11	-2.2122	1.4493749	27	14	1E+128	23.0029968; 2.8381972; 2.9940752; 11.9439952;	5.2267292
93	14	-2.8198	1.5557722	21	14	1E+128	23.0029968; 2.8381972; 2.9940752; 11.9407184;	5.2267196
94	20	-3.9465	1.3608712	11	13	1E+128	23.4769296; 2.4712012; 2.3754924; 11.9637472;	5.2267192
95	23	-4.415	1.0656807	20	12	1.11E+125	23.0050688; 2.832214; 2.9865284; 11.9637472;	5.2225792
96	20	-3.7377	1.2888568	20	13	1.11E+125	23.0050688; 2.832214; 2.9865284; 11.9637472;	5.2225792
97	18	-3.2611	1.3494288	20	11	1.11E+125	23.0050688; 2.8381972; 2.9867024; 11.9703008;	5.2098684
98	16	-2.854	1.3777807	14	13	1.11E+125	23.0050688; 2.8381972; 2.9867024; 11.9703008;	5.2098684
99	16	-2.7897	1.3467657	23	14	1.11E+125	23.0026112; 2.832214; 51.4295872; 11.9637472;	5.2098684
100	22	-4.2698	1.1778633	15	12	1.11E+125	23.0054784; 2.8320532; 2.9869392; 11.963748;	5.2090488

5. CONCLUSIONS

The concluding part examines the study's learnings as well as the limitations of the study. The optimization of the idle time of vessels from a linguistic perspective adds to our understanding of the particular need to attain precision in optimization using the genetic algorithm method via fuzzy integration. It is extremely useful since marine companies are experiencing the unprecedented challenge of dwindling economic fortunes. Instead of making fishing vessel decisions based on the crisp numeric values obtained from the genetic algorithm alone, the present study scrutinizes it from the perspective of linguistic variables. The parameters established based on the previous literature and mathematically analyzed add to the emerging picture of idle time management of the vessel controllers. Overall, this paper adds to the understanding of idle time minimization as a phenomenon from the perspective of fishing vessel companies with a strong will to reduce waste and losses in the marine industry. However, this study has limitations. Its attention is on fishing vessels and the dynamics of rescheduling vessel trips for profit enhancement or in the absence of goods and/or passengers to transport was not considered in the present study. This could be an interesting future research interest. Besides, the effect of government policies on the economics of fishing vessel maintenance services was ignored in this study and could be a worthwhile investment in future research efforts. Moreover, another optimization method could be hybridized with the fuzzy genetic method such as the Aquila algorithm. This may bring a new perspective to analyzing idle times of fishing vessels.

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