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IMPLEMENTATION OF NONDOMINATED SORTING GENETIC ALGORITHM – II (NSGA-II) FOR MULTIOBJECTIVE OPTIMIZATION PROBLEMS ON DISTRIBUTION OF INDONESIAN NAVY WARSHIP

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ABSTRACT

The high number of crimes and infraction that occurred in the Indonesian seas show the weakness of Indonesia's marine security. This is caused by the limited number of warships of the Republic of Indonesia (KRI), the lack of budget provided by the State, the wide area of the marines in Indonesia that should be secured, and the less precise decision from the Navy in determining the safety operational management of Indonesian seas. Therefore, problems in securing Indonesian seas not only in the form of a single objective problem but has become a model of multi-objective problem. So there’s a way needed to solve this problem by using the best solution search using *Nondominated Sorting Genetic Algorithms II* (NSGA-II), this method is used because it can generate a better solution with less calculations, elitism approach, and a little more parameters division compared with simple NSGA.

This study will determine the best combination of a 100 solution recommended by NSGA II in the focus of the type of the ship, speed, radar range, endurance, the area vulnerability level, geography, human resources, so it can be obtained one ideal solution in the focus of the placements composition of 27 warships to the 7 sectors in the ARMATIM area by maximizing the coverage area and minimizing the operational costs.

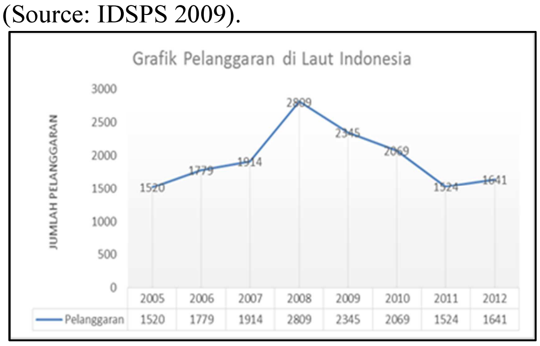
The results of the optimization of NSGA-II with 100 iterations, it is resulted that 23 warships selected and 4 warships docking with a combination of warships in each sector (S1 = 2, S2 = 7 S3 = 6, S4 = 2, 3 = S5, S6 = 2, S7 = 1), the broader outcomes of the coverage area is 1, 722, 880 Mil^2, so it can increase the security of territorial ARMATIM seas around 2% from the total secured area of 1,688,765 Mil^2, and operational cost Rp. 4.521.548.485,- the optimization model is thus able to save about 10% of the State budget of the specified the budget of Rp. 5.000.000.000,-.

Keywords: *Multiobjective Optimization Problems, NSGA II, Warship Distribution*

1. INTRODUCTION

The Republic of Indonesia (NKRI) is an archipelago consisting of 17,504 islands and has 81 290 kilometers along the coast *(Dishidros TNI-AL, 2003)*. As an archipelago with 80% sea line and 20% of landline, threat to Indonesian territorial integrity is there in the sea. The percentage of these threats become higher because of the position of Indonesian geography are in world trade traffic.

The high number of crimes and violations that occurred in the Indonesian seas shows that Indonesian seas is not safe and resulted huge losses for the State, frequent violations include: illegal fishing, illegal logging, illegal mining, illegal migrants, human trafficking and smuggling. (Source: IDSPS 2009).



Grafik 1. Violations in Indonesian Sea as Captured *(SOPS Armatim, 2012)*

Reviewed from the chart violations captured starting from 2005 - 2012, in the term of quality

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and quantity, the Indonesian Navy should be able to secure its sovereignty, but in fact Indonesian sea is still in a prone state. This is due to some factors, that is:

[1]. The unclear determination of Indonesian seas borders;
[2]. The weak coordination among government institutions that handle the security of Indonesian seas border;
[3]. The vast coverage area of Indonesian seas that needs to be secured;
[4]. The limited number of warships of the Navy of the Republic of Indonesia (KRI);
[5]. The lack of budget provided by the state for operational costs;
[6]. Less precise decisions in determining the safety operational management of Indonesian seas;
[7]. The lack ability of a commander to solve some of the problems in the Indonesian seas.

Based on the above factors the government is seen to be more accurate, fast and precise to decide what strategy will be taken in the Indonesian seas security operations.

The decision is a choice means, the choice of using of two or more possibilities. Decision making is the process of choosing an alternative way of acting with an efficient method according to the situation. Therefore, a Navy commander must be able to provide some alternative decisions regarding the assignment and placement of KRI in the area of operations so it can increase the intensity of Indonesian seas safety by considering the operational costs are provided by the government. Therefore, Indonesian marine safety problems are not only in the form of a single objective problem but also a model of multi-objective problems. For that we need a method to overcome this problem, which is by using the best solution search method. This is known as multiobjective Optimization Problems (MOP), based on several previous studies that MOP is included in metaheuristic which has been researched and developed by the researchers.

So multiobjective optimization problem is the problems that involves more than one the objective function to be minimized or maximized. Answers to be obtained from this problems is the collection of solutions that describe best tradeoff between the objective function competing (Deb, 2001). While in multiobjective optimization problems, the best solutions is determined / decided by dominace test.

Kalyanmoy Deb developed other variations of the algorithm developed by Goldberg called "Non-Dominated Sorting in Genetic Algorithms" (NSGA).

NSGA developed in Srinivas by Kalyanmoy Deb, which is one of the evolutionary algorithms. NSGA algorithm is based on several layers of individual's classifications (several layers). Before the selection is done, population is set at the base nondomination that is all nondominated individuals are classified into one category with a dummy fitness value that is proportional to population size, to establish an equal reproductive potential for these individuals. NSGA is a genetic algorithm which is very popular for the use on the multiobjective optimization problems. NSGA is a very effective algorithm but much criticized because of the complexity of the calculation, the lack of elitism and require optimal parameters.

NSGA-II is a modified and expanded version, which is better in the sorting algorithm, with elitism and do not require the distribution priority of parameters that must be selected. The population will be raised the first time, after the population will be sorted by non-domination on every front. The first front formed is based on a collection of non-dominant in the initial population and the second front will be dominated by individuals who are in the first front and so on.

2. RESEARCH METHODS

An optimization problem, modeled mathematically, generally consist of the objectives functions and constraints functions. The objective function represents the objectives to be optimized. As the number of functions more than one goal, the optimum solution of multicriteria optimization problems are also more than one, all of which goes into a set called Pareto frontier. This is in line with the principle that no single solution that can provide more optimal results from one of the existing objective function without sacrificing functionality of other purpose.

The main objective of this research is to determine the optimal combination of KRI placement to every sector of Indonesia's seas operations. This research requires the support of knowledge from the science of optimization, information systems, decision support system, artificial intelligence, shipbuilding and marine science in particular of Indonesian warships.

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From the aspect of information systems used in this study focus on achieving coverage area and operating costs warships. Changes information about specifications warship, warships operating costs and conditions will affect bases in ARMATIM assignment strategy and placement of Indonesian Navy warships in each operating region.

2.1. MATHEMATICAL MODEL

The mathematical model is a type of very important role in solving problems in everyday life, specifically for optimization system. Here are some mathematical models start from human resource needs, operational cost requirements and coverage area calculation formulas.

a. **Data spesifications warships:**
   - Speed KRI (Mil/Jam) = V_{kri}
   - Endurance (Hr) = E_{kri}
   - Radar Range (Mil) = d_{kri}

b. **Data human resources and natural resources warships:**
   - Personnel (Org) = JP_{kri}
   - BBM (Ltr/hari) = BBM_{kri}
   - Freshwater (Ton ltr/hari) = AT_{kri}
   - Lubricant (Ltr/hari) = MP_{kri}

c. **Coverage Area:**

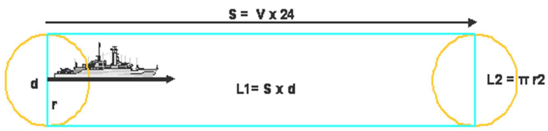

Figure 1. Concept Coverae Area

Based on Figure 1 above, there are equations as follows:

- S_{kri} = Speed KRI x 24 Jam (Mil)
  = Jarak Jelajah perHari
- $S_{kri} = \sum V_{kri} * 24$ Jam (Mil)
  d_{kri} = Jangkauan Radar (Mil)
  $L1_{kri}$ = Luas Persegi Panjang
  $L1_{kri} = S_{kri} * d_{kri}$ (Mil^2)
  $L2_{kri}$ = Luas Lingkaran
  $L2_{kri} = \pi * r^2$ (Mil^2)

Coverage Area wide range of KRI is a rectangular area (L1) coupled with area of a circle (L2) and multiplied by the probability of detection of radar:

1. **Coverage Area (CA)**
   - $CA_{kri} = \sum(L1+L2)$ * Probability Deteksi Radar (Mil^2)
   - $CA_{kri} = \sum(L1_{kri}+L2)*0.9$ (Mil^2)
2. **Liquid logistics cost (B_{lc})** warships can be found by referring to the available resources such as the following:
   - **Cost BBM** (B_{bbm}) = ∑Requirement BBM * ∑Cost BBM (Rp)
   - **Cost AT** (B_{at}) = ∑Requirement AT * ∑Cost AT (Rp)
   - **Biaya MP** (B_{mp}) = ∑ Requirement MP * ∑Cost MP (Rp)

So the formula becomes:

$$\sum B_{lc} = (\sum B_{bbm} + \sum B_{at} + \sum B_{mp}) \text{ Rp/day} \quad \dots (1)$$

As for Personnel Logistics Costs (B_{LP}) warships can be searched with knowing some of the the following equation:

- B_{TL} = Personnel Costs Benefits (day)
- B_{UMO} = Cost Money Eating Operations Personnel (day)
- B_{TP} = Benefits Cost Leadership Personnel (day)

So the formula becomes:

$$\sum B_{LP} = \sum B_{TL} + \sum B_{UMO} + \sum B_{TP} \text{ (Rp/day)} \quad \dots\dots (2)$$

2.2. INITIALIZATION PROBLEMS NAVY WARSHIPS DISTRIBUTION IN INDONESIA

To obtain an optimum distribution solution for the Navy warships, then the assignment problem for safety of Indonesian warships marine will be modeled in the form of mathematical equations in the form of multi-objective consisting of multiple objective functions and constraints. The equation of the multi-objective function is formulated achievement of coverage area of each ship with its operational costs.

Objective function and constraints established by the actual conditions of the assignment process Navy warships and the achievement of specified coverage area for each navy warship. Besides, it is necessary to define variables to generate a solution, because the optimization of NSGA II begins with a random population initialization in accordance with the definition of the solution variables.

Here is a model of the assignment problem Navy warships operating in in each sector ARMATIM.

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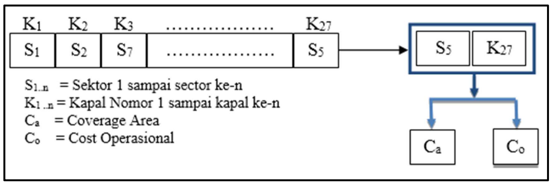

Figure 2. Initialization Warships Problem Combination In Each Sector

The first object is the goal Coverage Area Navy warships:

$$\text{Ca} = \sum_{n=1}^{7} Ca \ldots Max$$

$$\text{Ca} = \sum_{n=1}^{7} \sum(\text{L1}_{kri} + \text{L2}) * 0.9Mil^2 \ldots Max$$

$$\text{Ca} = \sum_{n=1}^{7} (\sum(S_{kri} + d_{kri}) + \sum\pi * r^2) * 0.9\ Mil^2 \ldots Max$$

$$\text{Ca} = \sum_{n=1}^{7} (\sum((v_{kri} * 24\ Jam) + d_{kri}) + \sum\pi * r^2) * 0.9Mil^2 \ldots Max$$

The second objective function is Operational Cost of Navy warships:

$$\text{Co} = \sum_{n=1}^{7} Co\ (Rp) \ldots \ldots Min \qquad \ldots\ldots\ldots\ldots$$

$$\text{Co} = \sum_{n=1}^{7} \sum B_{lc} + \sum B_{lp}\ (Rp) \ldots \ldots Min$$

$$\text{Co} = \sum_{n=1}^{7} \sum(B_{bbm} + B_{at} + B_{mp}) + \sum(B_{tl} + B_{umo} + B_{tp})\ (Rp) \ldots \ldots Min$$

$$\text{Co} = \sum_{n=1}^{7} \sum(B_{bbm} + B_{at} + B_{mp}) + \sum(B_{tl} + B_{umo} + B_{tp})\ (Rp) \ldots \ldots Min$$

2.3. MULTIOBJECTIVE OPTIMIZATION USING NSGA-II

Non-dominated Sorting Genetic Algorithm II (NSGA-II) is a multi-objective evolutionary algorithms. The first version is the NSGA (Deb.et.Al., 2000) which has received criticized for the same as other genetic algorithms that have Non-dominated Sorting and sharing, which has a complexity in calculation were less than the NSGA (Deb, 2011). NSGA-II is also doing development in terms of elitism and uses fewer parameters. NSGA-II is more popular and widely applied to various problems in research. In a study performed by Zitzler (1999) clearly proved that elitism can help to reach the best solution at the concentration of MOEAs (multi-objective Evolutionary Algorithms). Based on research conducted by (Vergidis et el, 2007), overall it appears that the NSGA-II gives satisfaction in the Pareto optimal solutions.

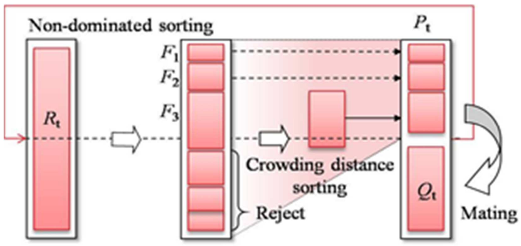

Figure 3. Block Diagram Of NSGA-II

The working principle of NSGA-II is the initializing of the population. As soon as the population initialised, the population sorted by non-domination into each front. Every individual in each of the front rated into a rank (fitness) or by the front where they are a part. The individuals in the initial front given a fitness value is 1, while for individuals on both fronts given fitness value 2 and so on for the next front.

Crowding distance is calculated for each individual which is used to measure how close an individual towards its neighbors. The larger average score of crowding distance will result in diversity of the better population. The parent is selected from population by using binary tournament selection based on rank and crowding distance. An individual selected at a smaller rank than another or if crowding distance is greater than the other. Selected population will generate offspring of crossover and mutation operators.

The parents will be selected from a population by using binary tournament selection based on rank and crowding distance value. An individual will be selected if it has a rank value smaller than other individuals or crowding distance value greater than other individuals. Crowding distance than if the rank of the two individuals are the same. Selected population will generate new offspring through crossover and mutation process.

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Initial population that contains the parent and offspring are sorted again by non-domination and only the N best individuals to be selected, where N is the population size.

2.4. STAGE ALGORITHM NSGA-II

The steps involved in the NSGA II algorithms are shown in fig.4. These steps are described below.

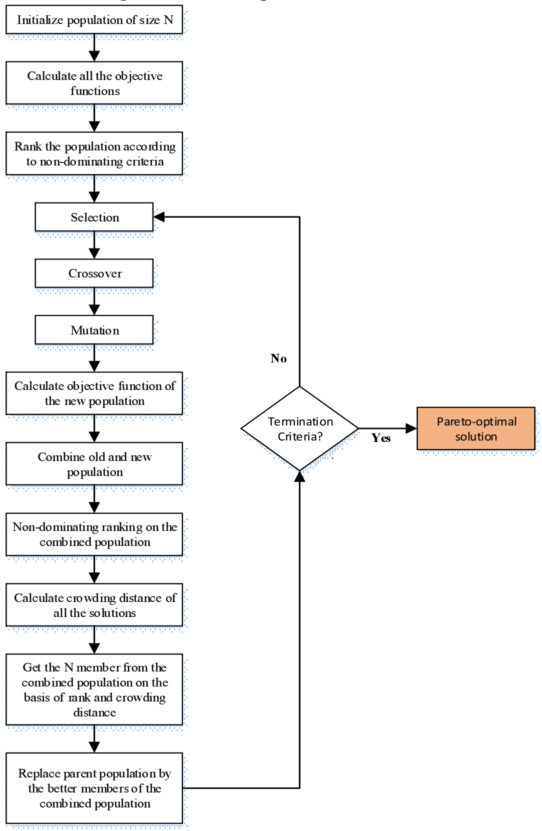

Figure 4: NSGA II Algorithm (After Deb, 2001)

Step 1: initialize the population. The initial population may be generated using uniformly distributed random numbers.

Step 2: Calculate all the objective functions values, separately.

Step 3: Rank the population using the constrained non-dominating criteria. The first non dominating front is generally assigned a rank of one. Similarly the second non-dominating front has a rank of two and so on. The solutions having lesser rank are the better candidates to be selected for the next generation.

Step 4: Calculate the crowding distance of each solution. The crowding distance is measured as the distance of the biggest cuboid containing the two neighboring solutions of the same non-dominating front in the objective space (Fig. 4). Higher the value of crowding distance better is the probability of the solution to be selected for the next generation. The solutions at the ends of the non-dominating front are assigned a large value of crowding distance so as to incorporate extremities of the non-dominating front.

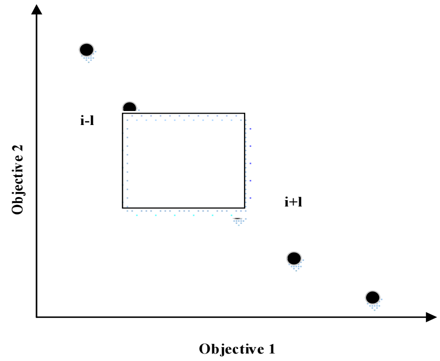

Figure. 5: Crowding Distance Of A Solution (After Deb,2001)

Step 5: Selection is done according to the crowding distance operator. The crowding distance operator function as follows: for a minimization type optimization problem, a solution x wins the tournament with another solution y if (a) solution x has better rank than solution y , or, (b) if the solutions x , and y have the same rank, but solution x has large crowding distance than solution y.

Step 6: Apply crossover and mutation operator to generate children solutions.

Step 7: The children and parent population are combined together in order to implement elitism and the non-dominating sorting is applied on the combined population.

Step 8: Replace the old parent population by the better members of the combined population. The solutions of the lower ranking fronts are selected initially to replace the parent population. If all the solutions of a front cannot be accommodated in the parent population, the solutions having large crowding distance will get preference to replace the parent solutions. Fig. 5 shows the replacement scheme of NSGA II. These steps are repeated till the termination criteria are satisfied.

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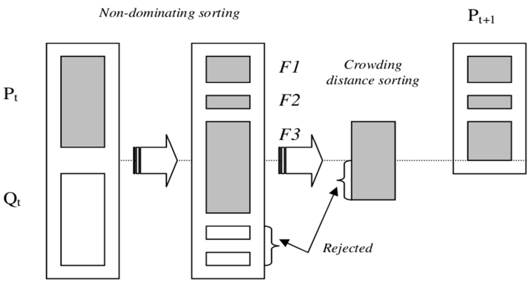


Figure 6: Replacement Scheme Of NSGA II (After Deb, 2001)

3. RESULT AND DISCUSSION

There are some supporting data used in the optimization process of the distribution of Navy warships in each sector of operation, that is:

a. Navy Warship Data
b. The data area of each sector to be secured.
c. Support base in each sector.
d. Data susceptibility regions, geographical conditions.
e. Operating cost data and assignment models.

The data above serve as a database of information to be processed and modeled in a mathematical model.

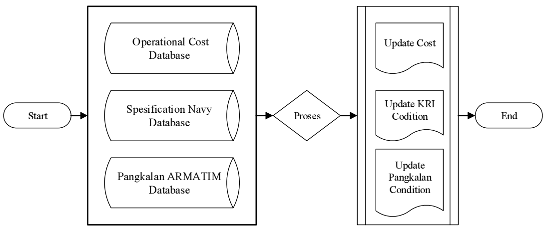


Figure 7. Model Entity Relationship Database

3.1. Chromosome Representation

Chromosome representation aim to encode a chromosome that contains the binary number into individual x is declared the activity to participate or not, where the binary number 0 indicates no activity and 1 indicates there is activity.

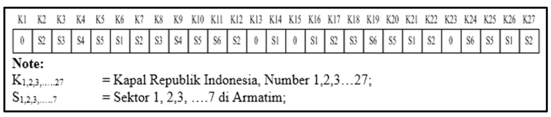
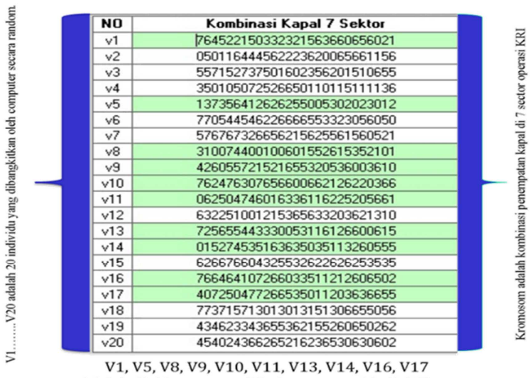


Figure 8. Representasi Kromosom

3.2. Initialization Individual

Chromosome initialization is done randomly, however, must still consider the solution domain and the constraints existing problems.



NO	Kombinasi Kapal 7 Sektor
v1	764522150332321563660656021
v2	050116444562223620065661156
v3	557152737501602356201510655
v4	350105072526650110115111136
v5	137356412626255005302023012
v6	770544546226666553323056050
v7	576767326656215625561560521
v8	310074400100601552615352101
v9	426055721521655320536003610
v10	762476307656600662126220366
v11	062504746016336116225205661
v12	632251001215365633203621310
v13	725655443330053116126600615
v14	015274535163635035113260555
v15	626676604325532622626253535
v16	766464107266033511212606502
v17	407250477266535011203636655
v18	773715713013013151306655056
v19	434623343655362155260650262
v20	454024366265216236530630602

V1........V20 adalah 20 individu yang dibangkitkan oleh computer secara random.
Kromosom adalah kombinasi penempatan kapal di 7 sector operasi KRI
V1, V5, V8, V9, V10, V11, V13, V14, V16, V17
adalah individu yang terpilih dan memenuhi nilai Fitness

Figure 9. Inisilisasi Populasi

The purpose of this function is to generate a population that contains a number of chromosomes. Each chromosome contains a gene number, the input to this function is a variable population size in the form of a two-dimensional matrix of population x number of genes that are binary worth (0, 1, 2, 3, 4, 5, 6, 7).

3.3. Optimization Result on NSGA-II

In this study, a multi objective optimization process based on NSGA-II is used is 27 warships to be distributed to the 7 sectors in the region ARMATIM with a total area of 1,688,765 Mil2 to be secured and operating costs provided by the Government of maximum Rp. 5.000.000.000,-.

Table 1. Navy Spesification With ARMATIM Zone

No	KELAS	SPEED V (Mil/Jam)	ENDURANCE E (Hr)	RADAR AREA d (Mil)	PERSON (org)	BBM (Ltr/Hr)	WATER AT (TonLtr/Hr)	OIL ML (Ltr/Hr)
1	PARCHIM	15	4	48	67	12,200	10	30
2	FPB	17	5	48	41	10,100	9	26
3	PC	25	3	48	22	8,400	5	37

Source: SOPS ARMATIM 2008

- The number of class PARCIM = 9 units
- The number of class FPB = 9 units
- The number of class PC = 9 units
- The class PC and FPB ≠ Sektor 4 dan 7

Therefore, how to model NSGA-II is able to find the most optimal solution with reference to the achievement of maximum area coverage and minimum operating costs, based on type warships are presented in Table 1.

To find the best combination of the NSGA-II, the GA algorithms require a fitness value to declare good or not a solution (individual). The fitness value which will be used as a reference in achieving optimal value in a genetic algorithm. Genetic algorithm aims to find individuals with the best fitness value.

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Therefore, this case aims to maximize the area coverage and minimize costs. So the algorithm NSGA-II should find the best combination between the two objectives are conflicting. Here is the formula that is used as a fitness value which is the purpose of maximizing coverage area and minimizing operational costs.

$$\textbf{Cost} = \sum_{n=1}^{7} \sum (B_{bbm} + B_{at} + B_{mp}) + \sum (B_{tl} + B_{umo} + B_{tp})\ (Rp) \ldots\ldots Min$$

$$\boldsymbol{Fitness\ 1} = \frac{1}{Cost} * 0.01 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$$\textbf{Ca} = \sum_{n=1}^{7} (\sum((v_{kri} * 24\,Jam) + d_{kri}) + \sum \pi * r^2) * 0.9 Mil^2 \ldots Max$$

$$\boldsymbol{Fitness\ 2} = Ca * 0.01 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Table 2. Results Of Running NSGA-II = 93 Warships Combination A Solution

NAVAL COMBINATION	COST	COVERAGE	USED	NOT USED	FITNESS
434353732623623215220010052	4521548485	1722880	23	4	1.885
176241343000631602660005661	4054627845	1581339	20	7	1.879
455637667515523013500100561	4590240773	1757828	22	5	1.879
213334760305200652600105236	3880413382	1536750	20	7	1.875
603263427202261506003302526	4034625381	1581487	21	6	1.875
603746563052513205051260620	4175724676	1632885	21	6	1.869
474560576156025216102322003	4364810521	1697265	22	5	1.868
651456117653221233112660020	4764554542	1848160	24	3	1.867
064164716326651506003302526	4421539543	1731626	22	5	1.86
651456117653202501200132321	4497099111	1759585	23	4	1.859
737415073136032602660005666	4227001792	1668640	21	6	1.857
405371106152311506003302526	4083014382	1627637	21	6	1.854
474560576556030326036015160	4254694412	1683467	21	6	1.854
245171332253602100506226305	4192125365	1664793	22	5	1.853
621716014226136056336502006	4335175641	1712567	22	5	1.853
736315543203101512221632060	4445158223	1751645	23	4	1.853
736615543203101511221632060	4503908125	1773026	23	4	1.853
064164716326652332025035350	4517908624	1782698	23	4	1.851
003263427202263653101063031	3946859255	1592452	21	6	1.85
037143510563215665500222360	4287335801	1702791	22	5	1.849
4074014565655530650126100660	3984929654	1604848	20	7	1.849

Based on the results of running the model NSGA-II with 100 iterations showed 93 a solution with different combinations warship models as shown in Table 2.

Based on the fitness value has been determined, then the algorithm NSGA-II is able to accelerate finding the desired solution as shown in chart 1 below.

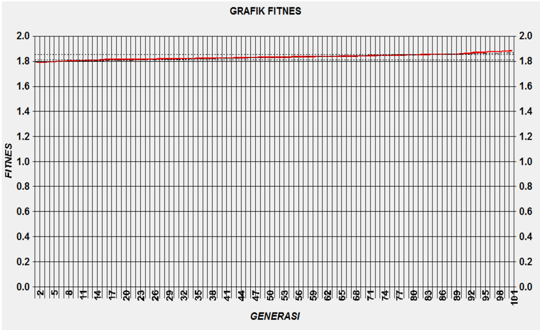

Chart 1. The Best Fitness Value = 1.885

Figure 1 above shows that the algorithm NSGA-II accelerates find fitness value has been determined, in this case the value of fitness achieved during the 10th iteration, so that the fitness value is better able to accommodate the fitness value and cost value coverage area of operations. To obtain the most ideal a solution the recommended NSGA-II based on the highest fitness value as figure 10 below.

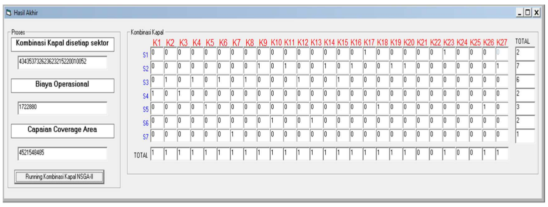

Figure 10. Result Optimization Nsga-Ii

Warships Combination : 434353732623623215220010052
Operational Cost : Rp. 4.521.548.485
Coverage Area : 1.722.880 Mil^2
Warships Used : 23
Warships Not Used : 4
Fitness : 1.885

Based on a combination of warships composition obtained in each sector of operations as follows:

- Sector 1 : 2 warships
- Sector 2 : 7 warships
- Sector 3 : 6 warships
- Sector 4 : 2 warships
- Sector 5 : 3 warships
- Sector 6 : 2 warships
- Sector 7 : 1 warships

23 warships Used

The combination of the above is influenced by a warship no 11 to 27, because it can not operate in sectors 4 and 7.

This optimization must meet the requirements fitness 1 and 2 that is how to choose a combination of warships capable of securing optimal Indonesian sea territory and how to find a combination of warships to be assigned and to be in repair.

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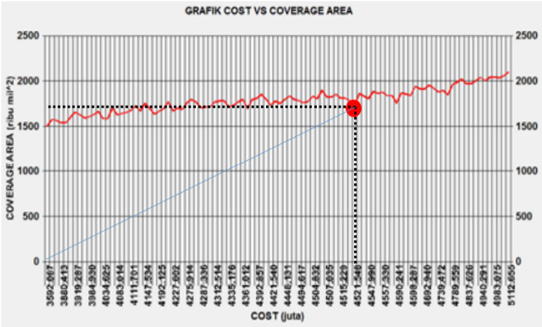

Chart 2. Optimum Point Of Cost And Coverage Area

That is a combination of warships, was the meeting of two points chosen fitness value coverage area and operating costs in the respective sectors. NSGA-II has to choose between some of the best a solution but the combination is what is considered the most feasible [4-3-4-3-5-3-7-3-2-6-3-6-2-3-2-1-5 -2-2-0-0-1-0-0-5-2].

The combination describes the composition of 27 ships in 7 sectors that is: [K_1= sector 4, K_2 = sector 3, K_3 = sector 4, K_4 = sector 3, K_5 = sector 5, K_6 = sector 3, K_7 = sector 7, K_8 = sector 3, K_9 = sector 2, K_{10} = sector 6, K_{11} = sector 3, K_{12} = sector 6, K_{13} = sector 2, K_{14} = sector 3, K_{15} = sector 2, K_{16} = sector 1, K_{17} = sector 5, K_{18} = sector 2, K_{19} = sector 2, K_{20} = OF, K_{21} = OF, K_{23} = sector 1, K_{24} = OF, K_{25} = OF, K_{26} = sector 5, K_{27} = sector 2].

The combination resulted in operational cost of Rp. 4.521.548.485,- and Coverage Area of 1.722.880 Mil^2. If mathematically analyzed this combination has been able to save 10% of the State budget and improve coverage area warship 2% and 4 warships choose to do repairs so as to increase the reliability of Navy warships.

4. CONCLUSION

- NSGA-II has to choose between some of the best a solution but the combination is what is considered the most feasible [4-3-4-3-5-3-7-3-2-6-3-6-2-3-2-1-5-2-2-0-0-1-0-0-5-2].
- The combination of the 23 commissioned warships to operate and 4 warships for docking resulting in operational cost of Rp. 4521548485 and achievements Coverage Area for 1.722.880 Mil^2.
- Mathematically this combination has been able to save the state budget by 10% and increase the coverage area of the ship's ability by 2% and pick 4 for docking warships so as to increase the reliability of Navy warships.
- NSGA-II algorithm computing to speed up the process of finding a feasible a solution of the fitness value is determined.

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