Artificial Immune System analysis on Route Construction distribution of gas cylinders using the AINet Algorithm

Chairun Nas1*, Nursaka Putra2, Yeyi Gusla Nengsih3 and Ilwan Syafrinal4

1 Catur Insan Cendekia University, Cirebon, Indonesian
2,4 Catur Insan Cendekia University, Cirebon, Indonesian
3 Imelda Medan University, Medan, Indonesian

Email: 1*chairun.nas@cic.ac.id, 2nursaka.putra@cic.ac.id, 3yeyigusla22@gmail.com,
4ilwan.syafrinal@cic.ac.id

Abstract. As a distributor of gas cylinders, the company will make every effort to distribute the products to customers effectively. In the distribution of gas cylinders, there are always problems in terms of saving distance and time in distribution. For this reason, an analysis is needed to optimize the distribution using the Artificial Immune System (AIS) method. The purpose of this research is to optimize the distance and time of distribution of gas cylinders by using the existing algorithm in AIS, namely the Artificial Immune Network Algorithm (aiNet). In this study, the distribution is limited specifically to the city of Cirebon. Furthermore, the AINet algorithm is analyzed for 20 distribution points using 3 vehicles. The results of the aiNet analysis show that the optimization within the distance is 1.28% and the time optimization is 0.37%. So using the Artificial Immune System with the AINet Algorithm, the distance and time can be optimized in the distribution of gas cylinders.

1. Introduction
The distribution of goods is one of the activities to distribute products carried out by certain companies. An aspect to consider in distributing goods is how to distribute goods to a number of customers with the aim of optimizing the distance and travel time, so as to minimize the total cost of distributing goods. Therefore, the problem that must be done by the company is choosing a distribution route that is really optimal, one example is the distribution of gas cylinders. Currently, the determination of the gas distribution route is still being carried out based on estimates, this has an impact on the distance and travel time that is not optimal. So an analysis method is needed to solve this problem. In this study, the analysis of optimization can use the Artificial Immune System (AIS) method. AIS is a model of intelligent computing inspired by immune system mechanisms with characteristics of learning, adaptation, memory, resilience, self-organization and scalability [1]. This AIS uses signaling, learning, and memory to complete classification and pattern recognition tasks and to remember previously known patterns [2]. AIS is also widely applied in the fields of computer security, anomaly detection, Web Mining, Internet of Things (IoT), classification, Numerical Function Optimization, and Combination Optimization [3]. In AIS, there is an algorithm as an intelligent search optimization method that mimics the mechanisms of biological immunity and gene evolution [4].

This research will discuss the algorithm in SIA, namely the Artificial Immune Network Algorithm (aiNet). Artificial Immunity Network Algorithm (aiNet) is inspired by idiotypic network theory which can describe several dynamic characteristics of the immune system, besides that aiNet has several unique features such as dynamically varying population size, both local and global searches, and the
ability to retain multiple optima. 4], aiNet is based on a graphical network structure, where the antibodies as nodes in the algorithm perform training which involves growing or trimming edges between nodes based on their affinity. The aiNet algorithm is widely used for problem grouping, data visualization, optimization, and can also be combined with artificial neural networks.

In previous research, the use of the AINet algorithm was implemented in the Construction Site Layout for the workspace construction process. Construction Site Layout is a process for work in the construction of a field or room. In this study, there are 10 points of location for the construction of the room that need to be optimized in processing time. Furthermore, the analysis is carried out using the AINet Algorithm. The results of this analysis resulted in the optimization of time for room construction of 8.7% compared to sequential works [5]. So the aiNet algorithm has been successful in optimizing the processing time-space.

Based on previous research, the AiNet Algorithm can be implemented to solve problems in determining the best and optimal route in gas cylinder distribution. With the aiNet algorithm on Route Construction, it will be able to generate new routes that can optimize the distance and time in the distribution of gas cylinders to customers.

2. Literature Review
The following can be explained the concepts of the natural immune system and artificial immune system as follows.

2.1. Immune System
The immune system in humans functions to protect the human body from various types of pathogens such as harmful germs and viruses that can flow in the body [1]. The immune system consists of several types of bioactive molecules, cytokines, and proteins where the cells collectively form a variety of biochemical networks that can defend themselves from pathogens [6]. To fight viruses and harmful germs, the immune system must be able to recognize and identify pathogens, where each pathogen has a molecule called an antigen [7]. Antigens have a unique form in pathogens that allows immune system cells to recognize various pathogens in the body. When a pathogen enters the body, the immune system will respond in 2 ways, namely the innate immune response and the adaptive immune response.

a. Innate Immune Response
The innate immune response has a response or reaction that is fast but not specific to the pathogen. Innate immunity is mediated by a population of innate immune cells such as myeloid cells, natural killer cells, and innate lymphoid cells (there are some non-immune cells in certain circumstances). When the pathogen infection process, innate immunity will know or be triggered in advance (inflammatory reaction) and The reaction does not require a long time to be fully active. Innate immunity is the initial defense in the new phase of infection until the disappearance of pathogens efficiently. But sometimes the defense fails due to the high number of infections that attack. It is in this situation that lymphocytes and adaptive immune mechanisms are activated that allow the recognition and elimination of specific pathogens [8].

b. Adaptive Immune Response
Adaptive immune response has a response that is slower but specific to pathogens and with a generation of immunological memory that lasts longer. Adaptive immunity is a relatively new evolution based on the family of immunoglobin (antibodies) and cells such as B lymphocytes (B-cells) and T (T-cells) [8]. T cells help in controlling the adaptive immune response and also kill pathogens and infected cells. Whereas the B cells function to make antibodies to specific antigens. Antibodies are proteins that attach to pathogens. These proteins can signal immune cells to destroy pathogens [7].
When an antigen is detected by the body for the first time or is called the main response, then the immune cells will increase the mass of antibodies (Cloned Antibodies) to destroy the antigen [1]. B-cells that make antibodies (derived from bone marrow) collectively form something known as immune tissue. This network works to ensure that B-cells are produced and operating and the immune system until B-cells are no longer needed [9]. When B-cells meet with antigens, the immune tissue will respond so that antibodies bind to antigens based on compatibility. Match between antibodies and antigens was measured by affinity. The higher an affinity, the better and more suitable candidate antibodies to specific antigens [1]. When antibodies are well-matched with antigens, B-cells are stimulated and produce mutated Cloning and enter into the immune tissue. New Cloning B cells can only be added to the immune network if B cells have an affinity for cells already in them, otherwise B cells will die.

2.2. Artificial Immune System

The Artificial Immune System (AIS) is described as an adaptive system that mimics the function of human immunity as a model principle in solving technical problems [10]. Immune tissue theory against various diseases is the initial inspiration for the creation of an AIS and also immune tissue theory can be implemented for machine learning, controlling problems and optimizing problem solving techniques. The methodology is ideal or suitable for models and fields of learning reinforcement, artificial neural networks, classification learning systems, computer security, Web Mining, optimization of numerical functions and genetic algorithms [11]. Basically, the immune system has several properties in it, namely [12]:

a. Detection, this happens in the immune system when infective fragments and sensory receptors in the lymph node are chemically bound.
b. Diversity, in the body's immune system, is related to the non-self bodies of the organism, so the immune system has several sensory receptors in which some lymph cells will react with foreign organisms.
c. Learning, the immune system can detect and eliminate foreign organisms as soon as possible from the body.
d. Tolerance, this is related to the particles that mark themselves as bodies contained in chromosomes.
e. Uniqueness, each individual processes his immune system with special vulnerabilities and abilities.

f. Recognition of Foreign Organisms, molecules (dangerous) that are not part of the body are recognized and eliminated by the immune system.

In the AIS, some methods can be grouped into 2 fields, namely optimization, and classification. Furthermore, algorithms in the AIS can be categorized into 2 categories, namely population-based categories, where there are Clonal Model and Negative Selection algorithms, then there are network-based categories, where there are Continuous Models and Discrete Models algorithms [3]. In general, the Clonal Model algorithm is applied to optimization problems, while the Negative Selection algorithm is applied to classification and grouping problems. Algorithms in the network-based categories are generally applied to classification problems.

Based on Figure 2. Then it can be put forward several main algorithm theories used in the artificial immune system such as, Negative Selection Algorithm (NSA) [1]; Artificial Immune Network Algorithm (aiNet) [5]; Clonal Selection Algorithm (CLONALG) [7]; Dendritic Cell Algorithm (DCA) [8].

2.3. Artificial Immune Network Algorithm (aiNet)

The Artificial Immune Network Algorithm (aiNet) was introduced by De Castro and Vo Zoben where this algorithm aims to reduce and classify separate data [13]. This aiNet generates a network of linked antibodies according to affinity (euclidean distance in the feature space). The subset of antibodies with the highest affinity was selected for the associated antigen and cloned proportionally to the affinity so that all of the resulting cloaks mutated inversely with their affinity [14]. The cloning result which has a fixed percentage is chosen to be memory antibody, if a memory antibody pair has an affinity greater than the threshold, then one of the antibody pairs will be removed from the tissue. Whereas memory antibodies that have an affinity for antigens that are less than the threshold, the memory antibodies will be eliminated [13]. This process can be illustrated in Figure 6 below:
In Figure 6 (a) there is a dataset with three clusters (A, B, C) with high data density. In Figure 6 (b) each cluster forms a cell network, the lines show connections to connect broken clusters by characterizing different groups in the network. The numbers in the memory cells represent their labels, while the numbers on the lines represent their strengths. It should be noted that the number of memory cells is generally higher than the number of clusters and much smaller than the number of samples [14]. The process flow of The aiNet is shown in Algorithm 1 [15].

**Algorithm 1: Proposed aiNet**

| Input | Description |
|-------|-------------|
| Size of The population of antibodies (N), Number pf cells that should be cloned (n), Percentage of cells to be moved to the memory set (m), Suppression Threshold (δs), Natural Death Threshold (δd), Percentage of randomly generate cells to be include in the population (d). |
| Output | Eliminate the network cells. |

**Step 1** : Randomly create the initial population of (N) antibodies;  
**Step 2** : Determine its affinity to all network cells;  
**Step 3** : Select the (n) highest affinity network cells;  
**Step 4** : Generate Nc clones from these n cells. The higher the affinity, the larger Nc;  
**Step 5** : Apply hypermutation to the generated clones, with variability inversely proportional to the progenitor’s fitness;  
**Step 6** : Determine the affinity among the antigen and all clones;  
**Step 7** : Keep only m% of the highest affinity mutated clones into the clone population;  
**Step 8** : Eliminate all clones but one whose affinity with the antigen is inferior to a predefined threshold δa (apoptosis);  
**Step 9** : Determine the affinity among all the mutated clones and eliminate those whose affinity with each other is above a pre-defined threshold δs (suppression);  
**Step 10** : Insert the remaining mutated clones into the population;  
**Step 11** : Determine the similarity among all the antibodies and eliminate those similarity above a threshold δs (suppression).  
**Step 12** : Introduce a percentage d% of new randomly generated cells (random insertion).  
**Step 13** : Eliminate the network cells, if any, which reconize no antigen.

Based on the above procedure, the final result of the AINet Algorithm is the formation of a network that reflects the structure of the dataset. From these results, the scale of the network node-set is much less than the initial dataset but can still describe the original dataset, so this can reduce the redundancy of the data. However, from the aiNet Algorithm, the dataset network is often affected by noise and this will cause difficulties in data grouping [13]. Until now the aiNet algorithm continues to be developed by many researchers.
3. Experimental Results

The aiNet algorithm will be implemented for route construction in the case of gas cylinder distribution. In this study, 20 distribution locations for gas cylinders with 3 vehicles were determined to distribute them. Each vehicle has a time limit of 450 minutes to distribute gas cylinders with a cylinder capacity of 70. The point of distribution of gas cylinders can be seen in Figure 4 below:

![Figure 4. Gas cylinder distribution point.](image)

Furthermore, the initial population (N) is determined randomly, where 4 types of routes are determined as follows:

Route 1: A – B – C – N – T – L – P – U – S – K – O – F – J – I – M – H – D – G – Q – R – A
Route 2: A – U – F – B – M – N – R – H – D – L – I – G – S – P – K – Q – J – T – C – A
Route 3: A – D – Q – O – F – U – H – N – I – G – R – M – L – C – P – B – S – T – J – K – A
Route 4: A – G – I – D – M – Q – C – O – J – F – S – K – L – N – B – R – T – H – U – P – A

From the random population that has been obtained, the affinity value for all tissue cells is determined. The result of determining the value of affinity is that new routes are obtained from a random population or what is called Route Construction. The stages for determining Route Construction are as follows:

1. Determine the mileage value \( \delta_d = d_{iu} + duj - \mu * d_{ij} \)
2. Before looking for the value of \( c_1(\mu) \), the value is determined \( c_1(i,\mu,j) = a_1 * \delta_d + a_2 * (t_j - t_i) \)
3. The value of \( c_1(\mu) \) is obtained by selecting the minimum value of \( c_1(i,\mu,j) \) on each of the random routes.
4. Based on the previous steps, the C - O route is obtained, which will form a new route can be seen in Table 1 below:

| No | Initial Route | New Route          |
|----|---------------|--------------------|
| 1  | A – B – C – N – T – L – P – U – S – K – O – F – J – I – M – H – D – G – Q – R – A | A – B – N – T – L – P – U – S – K – C – O – F – J – I – M – H – D – G – Q – R – A |
| 2  | A – U – F – B – M – N – R – H – D – L – I – G – S – P – K – Q – O – J – T – C – A | A – U – F – B – M – N – R – H – D – L – I – G – S – P – K – Q – J – T – C – O – A |

Table 1. Route change results.
route 2 and route 5 (EP) use multiple routes. The next stage is Local Search which aims to improve the route to make it more optimal. At this stage, the data used is the data in Table 4 which assumes that route 1, route 3, and route 4 use a single route, while route 2 and route 5 (EP) use multiple routes.

a. **Single-route**

Single-route is used for route 1, route 3 and route 4 and has no impact on other routes.

1) **Relocate**

Relocate aims to move a point $v_i$ before point $v_j$ in one route.

2) **Exchange**

Exchange is to swap the position of two points, $v_i$ and $v_j$, in one route.
3) 2-Opt
2-Opt is to cut a route that contains a number of consecutive points into two routes and combine these routes into a new route.

4) Or-Opt
Or-Opt is to exchange a number of points \{ v_i, \ldots, v_{i+w} \} as much as k to another position with \( k \leq 3 \).

b. Multi-route
Multi-route will be used for a pair or two routes, namely route 2 and route 5.
1) Relocate
   Relocate is to move a point \( v_i \) from route 2 before point \( v_j \) on route 5.
2) Exchange
   Exchange is to swap point \( v_i \) on route 2 with \( v_j \) on route 5.
3) 2-Opt*
   2-Opt* is to swap the back of each route.

From the Local Search process that has been carried out, a new route can be obtained for the distribution of gas cylinders by selecting the farthest point which can be seen in Table 5 below:

Table 5. A new route for gas cylinder distribution with the furthest point.

| Route | Route Order | Capacity | Distance | Period |
|-------|-------------|----------|----------|--------|
| 1     | A – N – L – S – D – T – A | 65 | 41,45 | 179 |
| 2     | A – G – R – A | 44 | 17,8 | 109 |
| 3     | A – U – M – C – Q – O – P – A | 65 | 46,9 | 189 |
| 4     | A – K – F – J – I – A | 64 | 41,8 | 179 |
| 5     | A – H – E – B – A | 55 | 36,8 | 154 |
|       | Total       |          | 293     | 184,75 | 807 |

Based on Table 5, a graph can be formed for a new route of gas cylinder distribution as in Figure 5 below:

Figure 5. (a) Old route graph, (b) New route graph for gas cylinder distribution.
Figure 5 (a) describes the old route graph, where the distribution of gas cylinders on each route looks not optimal and uneven. Furthermore, in Figure 5 (b) is the result of the new route from the aiNet algorithm analysis that has been carried out. From the results obtained, it can be seen that the comparison with the original route with the new route result from the aiNet algorithm as in Table 6 below:

### Table 6. Results Comparison.

| Point | Route Order | Capacity | Distance | Period |
|-------|-------------|----------|----------|--------|
| Original Route | A – N – D – R – F – U – A | 56 | 13 | 127 |
|       | A – K – G – A | 66 | 26,9 | 164 |
|       | A – M – T – B – A | 52 | 27 | 136 |
|       | A – H – C – Q – P – O – A | 64 | 48 | 186 |
|       | A – E – J – I – S – L – A | 55 | 72,5 | 197 |
| Total | 293 | 187,15 | 810 |
| New Route | A – N – L – S – D – T – A | 65 | 41,45 | 179 |
|       | A – G – R – A | 44 | 17,8 | 109 |
|       | A – U – M – C – Q – O – P – A | 65 | 46,9 | 189 |
|       | A – K – F – J – I – A | 64 | 41,8 | 179 |
|       | A – H – E – B – A | 55 | 36,8 | 154 |
| Total | 293 | 184,75 | 807 |

Based on the value of the distance and travel time between the old route and the new route, the optimal value of the distance and travel time can be found with the formula \( \text{Opt} = 1 - (\text{old route} / \text{new route}) \). Then the optimization value for distance traveled is 1.28%, while the optimization for distance is 0.37%. Based on this optimization, the AINet algorithm has succeeded in optimizing the distance and travel time in the distribution of gas cylinders.

### 4. Conclusion and Further Work

Based on the discussion that has been done, the implementation of the Artificial Immune System on Route Construction using the AINet algorithm for the distribution of gas cylinders has resulted in an optimization of the distance and travel time. The results of the discussion obtained an optimization value of 1.28% for the mileage and 0.37 for the travel time. According to researchers, the optimization results obtained are still very small, therefore the AINet algorithm can be combined with other algorithms such as algorithms in the Artificial Neural Network method.

### References

[1] Mingan, W., Shuo, F., Chunhui, H., Zhonghua, L., & Yu, X. (2017). An Artificial Immune System Algorithm with Social Learning and Its Application in Industrial PID Controller Design. *Hindawi : Mathematical Problems in Engineering*, 2017(1), 1–13. https://doi.org/10.1155/2017/3959474.

[2] Shahram, G., Shyamala, D., Nasir, B.S., & Nur, I. U. (2008). A Review on Concepts, Algorithms and Recognition-Based Applications of Artificial Immune System. *CSICC 2008*, (pp. 569-576). Springer. https://doi.org/10.1007/978-3-540-89985-3_70.

[3] Miralvand, M., Rasoolzadeh, S., & Majidi, M. (2015). Proposing a features preprocessing method based on artificial immune and minimum classification errors methods. *Journal of Applied Research and Technology*, 13(4), 477–481. https://doi.org/10.1016/j.jart.2015.09.005.

[4] Lu, H., & Joarder, K. (2014). A Modified Immune Network Optimization Algorithm. *International Journal of Computer Science*, 41(4), 1–6.

[5] Duc, Q.V., Van, T.N., & Xuan, H.H. (2016). An Improved Artificial Immune Network For
Solving Construction Site Layout Optimization. *International Conference on Computing & Communication Technologies, Research, Innovation, and Vision for the Future (RIVF)* 2016. http://doi.org/10.1109/RIVF.2016.7800266.

[6] Pankita, H.P., Mary, E.M., Karen, E.P., & Jamie, L.R. (2016). The Immune System in Cancer Pathogenesis: Potential Therapeutic Approaches. *Hindawi : Journal of Immunology Research*, 2016(1), 1–13. http://dx.doi.org/10.1155/2016/4273943.

[7] Amy, E.T. (2015). The Immune System: The human immune system is a complex and powerful defense mechanism. *Journal of American Medical Association (JAMA)*, 313(16),1686. http://doi.org/10.1001/jama.2015.2940.

[8] Mihai, G.N., Andreas, S., Katarzyna, P., Leo, A.B.J., & Joachim, L.S. (2019). Innate and Adaptive Immune Memory: an Evolutionary Continuum in the Host’s Response to Pathogens. *Cell Host & Microbe*, 25(1), 13–26. https://doi.org/10.1016/j.chom.2018.12.006.

[9] John, E.H., & Denise, E.C. (1996). Learning using an artificial immune system. *Journal of Network and Computer Application*, 19(2), 189–212. https://doi.org/10.1006/jnca.1996.0014.

[10] Nasir, R., Javaid, I., Fahad, M., Anam, A., Umar, S.K., & Mohsin, I.T. (2018). Artificial Immune System–Negative Selection Classification Algorithm (NSCA) for Four Class Electroencephalogram (EEG) Signals. *Frontiers in Human Neuroscience*, 12(439), 1–15. https://doi.org/10.3389/fnhum.2018.00439.

[11] Sahar, A., Daniyal, A., Li, C., Ahmed, B., & Bandar, A.A. (2020). Artificial Immune Systems Approaches to Secure the Internet of Things: A systematic review of the literature and recommendations for future research. *Journal of Network and Computer Application*, 157(1), 1–57. https://doi.org/10.1016/j.jnca.2020.102537.

[12] Nidhi, R., & Archana, S. (2015). Improved Clonal Selection Algorithm (ICLONALG). *International Journal of Current Engineering and Technology*, 5(4), 2459-2464.

[13] Yangyang, L., Dong, W., Yiran, Y., & Licheng , J. (2016). An Improved Artificial Immune Network Algorithm for Data Clustering Based on Secondary Competition Selection. *IEEE Congress on Evolutionary Computation (CEC)* 2016, (pp. 2744-2751). IEEE . http://doi.org/10.1109/CEC.2016.7744135.

[14] Yangfei, Z., Liangpei, Z., & Wei , G. (2011). Unsupervised Remote Sensing Image Classification Using an Artificial Immune Network. *International Journal of Remote Sensing*, 32(19), 5461-5483. http://doi.org/10.1080/01431161.2010.502155.

[15] Fabricio, O.F., Guilherme, P.C., Pablo, A.D.C., & Fernando, J.V.Z. (2010). Conceptual and Practical Aspect of the aiNet Family of Algorithms. *International Journal of natural Computing Research*, 1(1), 1-35. http://doi.org/10.4018/jncr.2010010101.