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Research on Optimal Manpower Allocation Based on Artificial Bee Colony - Taking a Secondary Maintenance Factory of the Taiwan Army as an Example

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Abstract The maintenance factories in the Republic of China Army are divided into five levels, in which the second level maintenance factory is responsible for the maintenance of wheel vehicles and communication equipment, and adjusts its maintenance items according to the nature of the unit. Although each of the second maintenance factory has its fixed manpower allocation, the difficulty to balance the normalization of personnel vacation and the completion rate of equipment maintenance time often occurs. This study intends to use a mathematical model to describe the problem of minimizing the personnel salary, and maximizing the completion rate of personnel vacation, as well as the completion rate of due equipment maintenance time while considering the minimum rate of manpower allocation and personnel vacation's regulations in the second level maintenance factory. The artificial bee colony is applied to solve the modelled complex nonlinear optimization problem. The experimental results show that this study can simultaneously minimize the total salary of the manpower in a maintenance factory, maximize the completion rate of the personnel's legal vacations and the equipment's due maintenance time, while meeting the military's regulations regarding the minimum manpower allocation and vacations. The results of this study can provide an important reference for the military in formulating the manpower allocation of the second level maintenance factory, to achieve the normalization of personnel vacation thus improving the recruitment advantages of the military, and attain the completion rate of the equipment maintenance thus strengthening the combat power.

Keywords Second level Maintenance Factory, Manpower Allocation, Personnel Salary, Personnel Vacation, Maintenance Time, Artificial bee colony algorithm

1. Introduction

In the history of mankind, war has posed a great threat to the safety of human life and property. Taiwan's current military environment is plagued by severe threats from China, and "wars to end wars" is the best way to prevent the outbreak of war. Therefore, the Ministry of National Defense of Taiwan pointed out that only by constructing a national army with high quality, small quantity and strong combat power can intimidate the enemy from starting a war lightly. Therefore, Taiwan invests a huge defense budget every year to purchase advanced weapon systems, continue to improve combat capabilities and training tasks, to prepare a new generation of rapid response forces to build a solid defense joint force and ensure national security. However, a complete logistics support and maintenance system is required to exert various joint combat capabilities. Taiwan's Army has a five-level equipment maintenance and repair system: first-level equipment operators, second-level maintenance factories, third-level warranty factories, fourth-level regional joint warranty factories, and fifth-level base factories. Among them, the secondary maintenance factory is responsible for the maintenance of wheeled vehicles and communication equipment, and adjusts maintenance items according to the nature of the unit. Each secondary maintenance factory has its own fixed staffing, but there is a conflict while normalizing staff vacations and completing the due maintenance time of the equipment. Therefore, this study intends to consider minimizing the total salary of the manpower in a maintenance factory, achieving the fulfillment rate of personnel vacation regulations, and maximizing the fulfillment rate of equipment due maintenance time while meeting the minimum staffing rate and personnel vacation regulations of the maintenance factory. A mathematical programming model is used to describe this multi-objective optimization problem. At the same time, the artificial bee colony is applied to solve the above complex nonlinear optimization problem. The results obtained in this study can provide an important reference for the National Army of Taiwan in formulating the staffing of secondary maintenance factories, to achieve the normalization of personnel vacation, thus improving the National Army's advantage in personnel recruitment, and increasing the reliability of the National Army's equipment maintenance at the same time for strengthening the combat effectiveness of the national army. In the literature, there are few studies on the manpower allocation of maintenance factories of the national army. For example, [1] took the army's maintenance of engine accessories of various armored vehicles as an example. Considering that the maintenance time is dependent on the workpiece processing sequence and workpiece transportation time, the total weighted Tardiness (TWT) is used as the objective function to construct a flexible process-based factory dynamic maintenance scheduling model while considering emergency order insertion. At the same time, based on the particle swarm algorithm, a particle swarm optimization algorithm (Adaptive Weight Particle Swarm Optimization Algorithm, AWPSO) with adaptive inertia weight and Variable Neighborhood Search (VNS) variable learning factors is developed, which is combined with the Variable Neighborhood Search (VNS) method are combined to develop a Hybrid Particle Swarm Optimization Algorithm (HPSO) to solve their constructed scheduling model. Among them, the optimal setting values of various parameters in AWPSO are determined through the response surface method of experimental design. They develop four improved particle swarm optimization algorithms to verify that the established HPSO particle swarm optimization algorithm can obtain approximate solutions with excellent solution performance and stability when solving the static scheduling problems. Finally, through the maintenance operation mode of the army's armored vehicle engine accessories and considering the dynamic factors of emergency orders, the impact of emergency orders on the total weighted delay time was explored to obtain the best dynamic maintenance sequence, such that the repair workpieces can be completed on schedule thus enhancing the combat effectiveness of the troops. [2] took the diesel generators of the National Army as the research object and discussed its overall maintenance system, preventive maintenance and fault repair, including the preventive maintenance intervals and the time to perform faulty repairs, as well as relevant costs and overall impact caused by the diesel generators. Under the premise of minimizing the total cost, the historical data of the diesel generator maintenance of the air defense weapon system of a certain unit of the national army are analyzed and simulated by using the total cost model of preventive maintenance planning to obtain the best preventive maintenance interval, and conduct case verification and analysis at the same time. [3] used the failure mode and effect analysis (FMEA) system method to evaluate the risk priority number (RPN), propose a set of preventive measures, and select key priorities thus developing a maintenance policy for preventive maintenance. Meanwhile, preventive measures are taken in advance to address potential failures. According to their empirical research results, the maintenance of firefighting vehicles can indeed make the preventive mechanism work well, thereby reducing the risk of failure of preparation planning by utilizing the dynamic preventive maintenance planning developed based on FMEA. [4] conducted research on the secondary factory in the Army's combined battalions through failure mode and effect analysis (FMEA). They investigated the failure factors and risk priority values (RPN) that affect the overall operation process of the secondary factory, and the interviews with experts were also conducted to obtain suggestions for improving the operation process, so as to improve the efficiency of combined battalions' equipment entering the factory, to supervise and manage the maintenance operations of the second-level factory, and to implement the supervision mechanism thus improving maintenance efficiency and proper equipment maintenance. [5] obtained the optimal understanding of equipment maintenance schedules through optimization based on the linear programming. They also applied optimization technique to optimize the schedule target value and adjust the schedule after the filtered schedule and repair shop capacity inspection. The sensitivity analysis is also conducted on equipment and maintenance costs by using design data and maintenance data. [6] integrates the application structure and behavior of the existing supply and maintenance system to construct a system model that guides supply and maintenance, thereby effectively integrating relevant units, repair and maintenance personnel, and achieving overall effectiveness. At the same time, the effective use of architectural models allows army to effectively integrate information systems and achieve overall integration of business organization structure to operational processes to establish the concept of data digitization and improve business efficiency. In addition, their study also proposed appropriate solutions to the problem of insufficient parts and consumable equipment, thus improving the equipment availability rate and establishing an early warning system such that the relevant units can be replenished timely and the national army's dependence on external demand can be reduced for exerting effective combat power when necessary. Through these efforts, the national defense self-sufficiency can be promoted, the burden on the logistics force can be reduced, and thereby enhance the combat capabilities of the national army. [7] considered a maintenance workload problem (MWP) in which each item in a set of items requiring repair must be assigned to a facility in a set of repair facilities. At the same time, project maintenance must also be scheduled for each facility. While the goal is to hopefully deliver everything on time and at the lowest cost, some degree of delay is inevitable. Therefore, there is a need for a system solution that allows for a certain level of total system latency to reduce total operating costs. The army equipment systems analyze the initial work on the MWP and put some constraints on the overall problem to determine a feasible solution. The authors employ two alternative models to generate solutions that can be shown to be close to the optimal solution. The first is a different constraint on the complete problem that generates good feasible solutions. The second is to perform Benders decomposition of the full problem even when the full problem is prohibitively large (i.e., so large that it would take a long time to optimize all the data). While the authors were unable to generate lower-cost solutions for the available instances than those found using existing models, their approach did demonstrate that both the previous solution and the solution it generated were close to optimal. At the same time, using these two models in series can solve much faster than applying the original model for the largest instance of MWP. [8] studied the modified typical FMP (flight maintenance planning) problem for military flight fleets of generally common sizes. The issue of engine maintenance is discussed when taking the disruption of depot level maintenance (DLM) facilities, resulting in a long-term shortage of repairable engine parts into account. They proposed an optimization strategy to schedule the use of engines and parts to maintain engine availability and maximize the basic requirements for flight and maintenance until the DLM supply line is restored. At the same time, they also simulated the interaction between the model and the available maintenance resource capacity to evaluate the results of the proposed maintenance plan thus exploring the impact of random events. The authors used Monte Carlo simulation and asynchronous particle swarm optimization algorithm to obtain the best solution. Through large-scale application testing, their proposed method can be proven to produce a good FMP solution, and can also quantify the operating status of the maintenance chain to assist in the long-term planning. [9] considered the multi-state systems (MSS) composed of multi-state components that often need to perform multiple tasks continuously in actual industrial or military combat environments. To increase the probability that the system can successfully complete the next task, all maintenance activities must be performed during the maintenance interval between any two consecutive tasks under the condition of limited maintenance resources. Therefore, selective maintenance is a widely used maintenance strategy in this context. This selective maintenance problem is a typical discrete mathematical problem and has received widespread attention. The authors consider a selective maintenance model of artificial reliability for multi-component systems. Furthermore, each maintenance worker can be in one of multiple discrete job levels due to human error probability (HEP). It is assumed that the state of the component after maintenance is random and follows a deterministic probability distribution. They propose an artificial reliability model and a method to determine the status distribution of parts after repair to resolve this problem. The goal of selective maintenance scheduling is to find the most reliable maintenance action for each part under the constraints of maintenance interruption time and cost. They utilize a genetic algorithm (GA) to solve this complex optimization problem and takes human reliability into consideration. Based on the experimental results, it is important that the human reliability must be considered in the selective maintenance plan of MSS. [10] focused on multiple different factors such as aircraft flying hour (AFH), flight cycles (FC), calendar life (calendar life), annual flying requirement (AFR), etc. to optimize flight and maintenance planning (FMP). The goal aims to maximize the aircraft utilization rate (UR) while meeting other operational and maintenance constraints. Their proposed algorithm is tested on a fleet of eight aircraft. In addition, a ten-year planning period is also simulated except for the one-year planning period. According to the experimental results, both genetic algorithm (GA) and improved artificial bee colony (ABC) algorithm can effectively solve FMP problems. [11] analyze the characteristics of military equipment maintenance work and design optimization goals based on the actual needs of the army to build a multi-objective flexible maintenance process optimization model based on maintenance processes. They combine the advantages of the NSGA-II (non-dominated sorting genetic algorithms-II) algorithm and the simulated annealing algorithm to propose an improved HNSGSA (hybrid NSGA-II and SA) algorithm. According to the requirements of the optimization model, the authors design coding methods for processing sequence, equipment selection and processing program scheduling, as well as corresponding cross mutation methods. The feasibility of their constructed model is verified through the actual data of the maintenance. At the same time, the authors further verified the superiority, accuracy and effectiveness of the proposed algorithm by comparing it with the NSGA-II algorithm and the simulated annealing algorithm, to provide a scientific reference for the military for performing equipment maintenance. [12] believe that industrial and military applications are to perform a series of tasks with limited rest between two adjacent tasks. To increase system reliability, parts can be selectively maintained during breaks. Most studies on selective maintenance typically utilize minimal repairs and replacements as maintenance measures when the duration of outages is assumed to be deterministic. However, many maintenance behaviors are imperfect maintenance, and due to the influence of environmental and other factors, the interruption time is random in the actual situations. Therefore, they propose a selective maintenance optimization model for imperfect maintenance with random outage durations. Their model desires to maximize the reliability of the system to successfully complete the next mission. Their study applies reinforcement learning (RL) methods for optimizing the maintenance operations of selected components. In addition, three case studies are used to verify the excellence of their proposed model and reinforcement learning. [13] explore the problem of military aircraft flight and maintenance planning (MAFMP), with the purpose of maximizing aircraft availability. They consider heterogeneous maintenance tasks, that is, usage-based maintenance tasks (UBMT) performed before the aircraft's accumulated flight time reaches a predetermined limit value, and calendar-based maintenance tasks (CBMT) performed before the aircraft's accumulated calendar time. The MAFMP problem is a complex problem that often requires military operators to solve, and its optimization is critical to military readiness. They develop a mixed integer linear programming (MILP) model to address this problem and obtain some management insights that can be recommended to military operators through experiments with different parameter values. At the same time, the authors also propose two heuristic algorithms that can resolve large-scale problems in a reasonable time. The experimental results of several example problems show that their algorithm is efficient and effective. [14] pointed out that aircraft fleets often need to perform a series of missions with only limited rest time between two adjacent missions in many military scenarios. The fleet performance can be improved through conducting appropriate maintenance activities on damaged aircraft during each rest period. However, maintenance planning is inherently limited by maintenance capabilities (such as maintenance personnel and maintenance facilities) in such a case. Each maintenance activity includes multiple maintenance tasks that must be performed in sequence, and the structural dependencies of each aircraft's components impose additional constraints on the sequence of maintenance activities. Therefore, they develop a new maintenance program architecture for military aircraft fleets to maximize expected fleet readiness. Each maintenance activity requires specific maintenance facilities and maintenance personnel, and limited maintenance capabilities must be arranged through overall planning. In addition, the uncertainty associated with rest periods is also considered due to the unexpected arrival of the next mission on the battlefield. Their study proposes two heuristic algorithms to efficiently solve this optimization problem. According to the comparison results, their proposed heuristic algorithm can outperform other alternative algorithms and is expected to resolve large-scale problems.

2. Methodologies

Artificial Bee Colony

In nature, bees follow a specific, repetitive process for feeding. In the beginning, the potential forager is an unemployed bee because it cannot know the food sources around the hive. Unemployed bees can spontaneously search for food sources around the hive, or they can become new members when motivated by the waggle dance performed by other foragers. Once a scout bee finds a food source, it becomes an employed bee and remembers the location, thus beginning to exploit the food source. The employed bees then obtain large amounts of nectar from the food source, return to the hive, and unload the food. At this time, the employed bees will attract more onlookers through a waggle dance, or continue to forage on their own without attracting any onlookers. Once the food source is depleted of nectar, the employed bees will abandon the food source and become unemployed. Unemployed bees may become scouts to search for new food sources or become spectators that remain in the hive's dancing area and are attracted to the waggle dance performed by other employed bees. When bystanders have access to information from all currently abundant sources through waggle dance communication, they can focus on the most profitable sources and once again become employed bees to feed.

Inspired by the intelligent foraging behavior of bees, [15] described a bee colony algorithm, called the artificial bee colony (ABC) algorithm, for optimizing multi-variable numerical functions. In the ABC algorithm, artificial bee colonies include three types of bees: employed bees, onlooker bees and scout bees. The front half of the colony is made up of employed artificial bees, and the back half is made up of onlookers. There is only one employed bee per food source, and once the food source is abandoned, the employed bee becomes a scout. Furthermore, the location of the food source represents the possible solutions to the optimization problem under consideration, and the nectar amount of the food source corresponds to the quality (fitness) of the solution. Assume that there are *n* decision variables in an optimization problem, the general implementation steps of the ABC algorithm are summarized as follows [15-17]:

Step 1: Randomly generate an initial population consisting of feasible solutions (locations of food sources), where each solution is an *n*-dimensional vector.

Step 2: Evaluate the fitness of the initial solution generated in Step 1.

Step 3: Each employed bee generates candidate food locations based on old food locations in its memory:

$$v_i^j = x_i^j + rn_i^j(x_i^j - x_q^j), \forall i = 1,2,\ldots,N_f, \forall j = 1,2,\ldots,n, \quad (1)$$

Step 4: Evaluate the fitness of the candidate solutions established in Step 3. If the fitness corresponding to the candidate food location is better than the fitness of its old food location, the employed bee will remember the candidate food location $v_i = (v_i^1, v_i^2, \ldots, v_i^n)$. Otherwise, the employed bee will keep the old food location in its memory, i.e. $x_i = (x_i^1, x_i^2, \ldots, x_i^n)$.

Step 5: The probability that the onlooker chooses the food source is

$$pb_i = \frac{fit_i}{\sum_{i=1}^{N_f} fit_i}, \forall i = 1,2,\ldots,N_f, \quad (2)$$

where pb_i is the probability of a onlooker choosing the *i*-th food source as the target, and fit_i is the fitness with respect to the *i*-th food source.

Step 6: Each onlooker modifies the location of the selected food source according to equation (1).

Step 7: Evaluate the fitness of the modified solution from Step 6. If the modified solution corresponds to a higher fitness than its previous location, the onlooker remembers the new location.

Step 8: Remember the locations of the best food sources that employed bees and onlookers have found so far.

Step 9: If the employed bee cannot improve the fitness of the corresponding food location during the search cycle, it will give up the food source $(x_{i^*}^1, x_{i^*}^2, \ldots, x_{i^*}^n)$, and become a scout bee.

Step 10: Each scout bee becomes an employed bee again and finds new food sources based on

$$x_{i^*}^j = x_{min}^j + sn^j(x_{max}^j - x_{min}^j), \forall j = 1,2,\ldots,n, \quad (3)$$

where x_{max}^j and x_{min}^j are the upper and lower limits of the *j*-th decision variable, respectively; sn^j is a random number between (0,1).

Step 11: Repeat Steps 3 to 10 for *MCN* cycles, and designate the memorized best food source location as the final best solution.

Model of Optimal Manpower Allocation

This study intends to determine the optimal manpower allocation in a military maintenance factory, and its optimization model is expressed in mathematical model as follows:

Maximize

$$Max \frac{PM}{TS \times VC} \quad (4)$$

Subject to

$$\sum_{i=1}^{k}\sum_{j=1}^{m_i}\frac{X_{i,j}}{Q_{i,j}} \geq OR \quad (5)$$

$$P_{i,j} - Y_{i,j}\begin{cases}\leq VL_1 \text{ if } P_{i,j} \geq VT \\ \leq VL_2 \text{ otherwise}\end{cases} \quad (6)$$

where

$$X_{i,j} = \begin{cases}0 \text{ if the } j-th \text{ vacancy at level } i \text{ is unoccupied} \\ 1 \text{ if the } j-th \text{ vacancy at level } i \text{ is occupied}\end{cases} \text{ for } i = 1,2\ldots,k; j = 1,2,\ldots,m_i \quad (7)$$

$$Y_{i,j} = \begin{cases}1 \text{ if the occupier of the } j-th \text{ vacancy at level } i \text{ is a private } E-1 \\ 2 \text{ if the occupier of the } j-th \text{ vacancy at level } i \text{ is a private } E-2 \\ \vdots \\ 10 \text{ if the occupier of the } j-th \text{ vacancy at level } i \text{ is a second lieutenant}\end{cases}$$

for $i = 1,2\ldots,k; j = 1,2,\ldots m_i$ (8)

$$P_{i,j} = \begin{cases}1 \text{ if the } j-th \text{ position vacancy at level } i \text{ is a private } E-1 \\ 2 \text{ if the } j-th \text{ position vacancy at level } i \text{ is a private } E-2 \\ \vdots \\ 10 \text{ if the } j-th \text{ position vacancy at level } i \text{ is a second lieutenant}\end{cases}$$

for $i = 1,2\ldots,k; j = 1,2,\ldots,m_i$ (9)

$$Q_{i,j} = \begin{cases}0 \text{ if } P_{i,j} < 1 \\ 1 \text{ if } P_{i,j} \geq 1\end{cases} \text{ for } i = 1,2\ldots,k; j = 1,2,\ldots,m_i \quad (10)$$

OR is the lower bound for the ratio of occupation; *VT* is the critical value for the limit of class difference; VL_1 is the limit of the class difference for the occupier of the *j*-th vacancy and the *j*-th position vacancy at level *i* when the class difference is equal or greater than the critical value *VT* for the limit of class difference; VL_2 is the limit of the class difference for the occupier of the *j*-th vacancy and the *j*-th position vacancy at level *i* when the class difference is smaller than the critical value *VT* for the limit of class difference.

Furthermore, the total salary in Equation (4) is formulated as

$$TS = \sum_{i=1}^{k}\sum_{j=1}^{m_i} Y_{i,j}\, S_{i,j} \quad (11)$$

where

$$S_{i,j} = \begin{cases}S^1 \text{ if } Y_{i,j} = 1 \\ S^2 \text{ if } Y_{i,j} = 2 \\ \vdots \\ S^{10} \text{ if } Y_{i,j} = 10\end{cases} \text{ for } i = 1,2\ldots,k; j = 1,2,\ldots,m_i \quad (12)$$

The unachieved ratio of vacations can be expressed as

$$VC = \frac{\sum_{i=1}^{k}\sum_{j=1}^{m_i}\sum_{l=1}^{d} V_{i,j,l}}{\sum_{i=1}^{k}\sum_{j=1}^{m_i}\sum_{l=1}^{d} X_{i,j}} \quad (13)$$

where

$$V_{i,j,l} = \begin{cases}0 \text{ if the } j-th \text{ occupier at level } i \text{ has a vacation on the } l-th \text{ working day} \\ 1 \text{ if the } j-th \text{ occupier at level } i \text{ does not have a vacation on the } l-th \text{ working day}\end{cases} \text{ for } i =$$

$1,2\ldots,k; j = 1,2,\ldots,m_i; l = 1,2,\ldots,d$ (14)

In addition, the achievement ratio of equipment maintenance is formulated as

$$PM = \sum_{l=1}^{d}\sum_{q=1}^{c}\frac{\sum_{i=1}^{k}\sum_{j=1}^{m_k} V_{i,j,l} \times L_{i,j,q}}{LR_{l,q}} \quad (15)$$

where

$$L_{i,j,q} = \begin{cases}0 \text{ if the } j-th \text{ occupier at level } i \text{ does not have a maintenance license of type } q \\ 1 \text{ if the } j-th \text{ occupier at level } i \text{ has a maintenance license of type } q\end{cases} \text{ for } i =$$

$1,2\ldots,k; j = 1,2,\ldots,m_i; q = 1,2,\ldots,c$ (16)

$$LR_{l,q} = \begin{cases} 0 \; if \; the \; maintenance \; license \; of \; type \; q \; is \; not \; required \; on \; the \; l-th \; working \; day \\ 1 \; if \; the \; maintenance \; license \; of \; type \; q \; is \; required \; on \; the \; l-th \; working \; day \end{cases} \quad for \; i = 1,2 \ldots, k; q = 1,2, \ldots, c \qquad (17)$$

Finally, k is the total number of establishment levels; m_i is the total number of vacancies in the *i*-th establishment level; d is the maximum number of working days in an equipment maintenance cycle; c is the total number of types regarding maintenance licenses; S^1 is the salary for a private E-1; $S^2$is the salary for a private E-2; S^3 is the salary for a private E-3; S^4 is the salary for a corporal; S^5 is the salary for a sergeant; S^6 is the salary for a staff sergeant; S^7 is the salary for a sergeant first class; S^8 is the salary for a second lieutenant; S^9 is the salary for a first lieutenant; S^{10} is the salary for a captain.

3. Case Study

Data Collection

A secondary maintenance factory of the Taiwan army is taken as an example to explore the optimization of manpower allocation with the artificial bee colony algorithm. Since the maximum maintenance cycle of factory in this study is two years, the data gathered from the working days during January 1, 2021 to December 31, 2022. Due to confidentiality reasons, the daily personnel vacations, the daily number of required licenses for wheeled equipment entering the factory, and the daily number of licenses required for daily communication equipment entering the factory are virtual. According to the maintenance manual of R.O.C. Army Command, the current warranty system can be divided into three sections and five levels according to the degree of maintenance, rights and responsibilities. Levels 1 and 2 are collectively called unit section maintenance, levels 3 and 4 are collectively called field section warranty, and level 5 is the renovation for the base section.

The secondary maintenance factory is taken as an example. It is composed of professionally trained maintenance manpower. All maintenance operations must have this certificate. They are mainly responsible for the secondary maintenance and repair operations of the equipment for the supported units. The main work content is equipment cleaning, inspection, lubrication, other maintenance, as well as approved replacement of spare parts and sub-assemblies. When equipment enters the factory, there are two main reasons: regular maintenance and unscheduled inspection. They are dispatched to inspect in accordance with the maintenance operation specifications. In case of conditions beyond their rights and responsibilities, the transfer process will be handled by level 3 or above. The manpower of a secondary maintenance factory is organized as shown in Figure 1.

Different salaries and vacations are given according to soldiers' ranks and seniorities. The organization includes levels from private E-1 to captain in a secondary maintenance factory. The salary schedule is shown in Table 1. In addition. The normal number of days for vacations in different level is adopted since there is no absolute correlation between seniority and levels. The normal number of days of leave for each class is used as data, as shown in Table 2. The real vacations in 2021 and 2022 are collected in this study.

The maintenance equipment in this study is mainly wheel vehicles and communication equipment. The regular maintenance of secondary equipment includes monthly (M maintenance), quarterly (Q maintenance), half-yearly (S maintenance), annual (A maintenance), and every two years (B maintenance). Therefore, the data are simulated in an interval of two years. The equipment must complete regular maintenance within the scheduled maintenance period. If the task needs to be adjusted, it will be limited to one-tenth of the maintenance period. For example, M maintenance can be carried out 3 days in advance or postponed to the original date. Equipment maintenance certificate is required for performing the corresponding maintenance. Because the condition of the vehicle cannot be confirmed in advance, each maintenance technician can only complete the maintenance work of a vehicle per day. In addition, the maintenance personnel who is responsible for a vehicle can no longer perform the maintenance work for the communication equipment due to the limited maintenance time. Hence, this study also collects the daily required certificates for performing the maintenance of the wheel vehicles and communication equipment. Furthermore, the data for personnel on vacation and maintenance certificates are also collected.

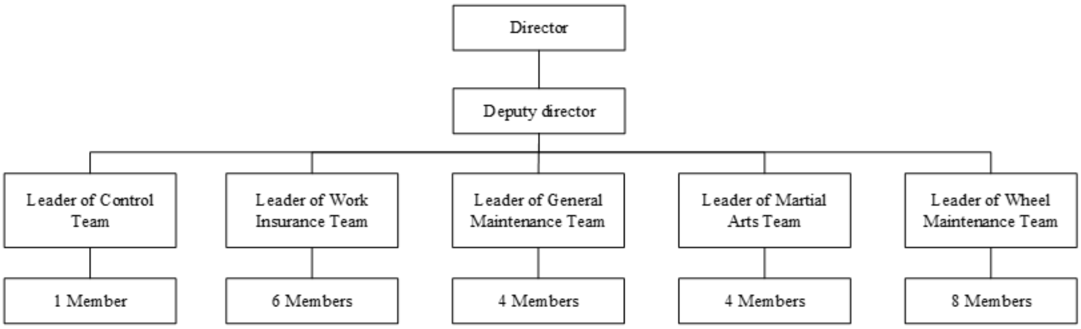

Figure 1: Organization of a secondary maintenance factory

Table 1: Salary schedule

Level	Salary (NT$)
Private E-1	34,340
Private E-2	35,995
Private E-3	37,655
Corporal	40,235
Sergeant	43,885
Staff sergeant	47,375
Sergeant first class	48,965
Second lieutenant	48,990
First lieutenant	51,915
Captain	57,285

Table 2: Complimentary days in a secondary maintenance factory

Level	Days
Private E-1	43
Private E-2	43
Private E-3	50
Corporal	50
Sergeant	57
Staff sergeant	64
Sergeant first class	66
Second lieutenant	7
First lieutenant	14
Captain	21

4. Optimization through ABC

The ABC algorithm coded by using Visual C++ programming language is then applied to resolve the manpower allocation in a military secondary maintenance factory, as formulated in Equations (4)-(6). In ABC, each solution is represented n-dimensional binary vector that is composed of the decision variables appeared in Equations (4)-(17) which totally have n decision variables. The parameters N_f and MCN of ABC are set as 50 and 50n, respectively. In addition, ABC algorithm stops searching if the best solution cannot be improved in 100 search cycles. Hence, the optimal manpower allocation can be obtained as shown in Table 3. The total salary TS, the unachieved ratio of vacations VC, and the achievement ratio of equipment maintenance PM in Equation (4) are 987535, 100% and 100%, respectively. The total salary can be appropriately reduced since three vacancies are unoccupied according to Table 3. Furthermore, both the unachieved ratio of vacations and the achievement ratio of equipment maintenance can reach their maximum values of 100%. The sensitivity analysis is then conducted by adjusting the salary and vacation ratio. The salary adjustment will directly cause the cost to increase by the same proportion, but the maintenance works can still be performed without increasing the total salary when increasing the salary in each level by 20% based on the analysis results.

Table 3: Optimal manpower allocation

$Y_{1,1}$	$Y_{2,1}$	$Y_{3,1}$	$Y_{3,2}$	$Y_{3,3}$	$Y_{3,4}$	$Y_{3,5}$	$Y_{3,6}$	$Y_{3,7}$	$Y_{3,8}$
unoccupied	*unoccupied*	Sergeant	*unoccupied*	Corporal	Corporal	Corporal	Sergeant	Corporal	Corporal
$Y_{3,9}$	$Y_{3,10}$	$Y_{4,1}$	$Y_{4,2}$	$Y_{4,3}$	$Y_{4,4}$	$Y_{4,5}$	$Y_{4,6}$	$Y_{4,7}$	$Y_{4,8}$
Corporal	Corporal	Private E-1	Private E-1	Private E-1	Private E-1	Private E-1	Private E-1	Private E-1	Private E-1
$Y_{4,9}$	$Y_{4,10}$	$Y_{4,11}$	$Y_{4,12}$	$Y_{4,13}$	$Y_{4,14}$	$Y_{4,15}$	$Y_{4,16}$	$Y_{4,17}$	$Y_{4,18}$
Private E-1	Private E-1	Private E-1	Private E-1	Private E-1	Private E-1	Private E-1	Private E-1	Private E-1	Private E-1

4. Conclusions

This study mainly focuses on the manpower planning in the military secondary maintenance factory. A case study in implemented according to the maintenance data performed by personnel on each working day of the equipment from January 1, 2021 to December 31, 2022, as well as the manpower requirements and specifications of the R.O.C. Army's secondary maintenance factory. A mathematical model is constructed and the artificial bee colony algorithm is applied to resolve the complex nonlinear programming problem to determine the manpower configuration that can achieve the highest equipment maintenance rate and vacation rate, while also reducing total salary. The experimental results show that the total salary can be reduced due to three unoccupied vacancies in the organization of a secondary maintenance factory. In addition, the unachieved ratio of vacations, as well as the achievement ratio of equipment maintenance can both achieve 100% that is higher than the requirement of R.O.C. army. The salary adjustment will directly affect the objective function, but there is still about 20% tolerance to consider in adjusting the number of vacation days. This adjustment can be considered as a reference for decision-makers when officers and soldiers generally feel that they are working overtime. Although the obtained manpower allocation in this study can effectively reduce personnel costs, the main reason is that a person with a low level occupies a higher position in the military is usual. However, the actual manpower allocation still needs to consider the professionalism of personnel. It may result in insufficient personnel experience, such as unable to effectively deal with emergencies if manpower allocation acquired in this study is directly applied. In addition, the actual status of acquiring maintenance certificates is not as good as the setting of this study. Hence, personnel training should continue to be strengthened to obtain various certificates.

This study is expected to provide a new method for evaluating the operations of a unit. Besides of maintenance factory, the research result can also be applied in manpower planning for daily on-site training of combat units. Through considering factors, such as staffing, tasks and various constraints, manpower utilization can be effectively evaluated. The chief officer can also utilize the results obtained in this study as a reference for adjusting the vacations of personnel and providing the best configuration to achieve the mission with the most appropriate grouping. The results can also more effectively support the demands of the battle plan.

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