Investigating Feed Mix Problem Approaches: An Overview and Potential Solution

Rosshairy Abd Rahman, Chooi-Leng Ang, and Razamin Ramli

Abstract**—**Feed is one of the factors which play an important role in determining a successful development of an aquaculture industry. It is always critical to produce the best aquaculture diet at a minimum cost in order to trim down the operational cost and gain more profit. However, the feed mix problem becomes increasingly difficult since many issues need to be considered simultaneously. Thus, the purpose of this paper is to review the current techniques used by nutritionist and researchers to tackle the issues. Additionally, this paper introduce an enhance algorithm which is deemed suitable to deal with all the issues arise. The proposed technique refers to Hybrid Genetic Algorithm which is expected to obtain the minimum cost diet for farmed animal, while satisfying nutritional requirements. Hybrid GA technique with artificial bee algorithm is expected to reduce the penalty function and provide a better solution for the feed mix problem.

Keywords**—**Artificial Bee Algorithm, Feed Mix Problem, Hybrid Genetic Algorithm.

I. Introduction

FEED is one of the factors that play an important role in determining a successful development of an aquaculture industry. As discussed by [13, 30], it has been proven that feed constitutes the most expensive component of the industry, approximating 50 to 60 percent of operational costs. Therefore, it is always critical to produce the best aquaculture diet at a minimum cost in order to trim down the operational cost and gain more profit.

The development of a satisfactory diet for the production of aquaculture demands a comprehensive understanding of nutritional requirements to assess the quality of the ingredients that comprise a feed [39]. Nutritional characteristics of the diet formulated include ingredient selection and nutrient level. Complete diets may consist of a combination of ingredients to generate a high nutrient value.

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There are two parties involved in formulating aquaculture complete diets; they are the aquaculture nutritionist and the scientist or researcher. The nutritionists have to find a list of appropriate ingredients for aquaculture feed and also the range of suitable nutrients for aquaculture growth. As stated by [65], one solution considered in reducing aquaculture production costs and increase producer's profitability is the use of feeds with low levels of fish meal and high levels of less expensive, high quality plant protein sources. On the other hand, the researchers have to hit upon the best solution using appropriate technique to get the optimal diet formulation at the minimum cost. Thus, instead of searching for cheaper ingredients, an alternative way to produce the least cost feed is through using enhanced technique in the formulation of the ingredients. This problem is addressed as the feed mix problem and there has been quite an extensive work or studies being carried out in relation to the problem. Hence, the next section discusses quite a lot of related work which divided into two; individual approaches and integrated approaches. Individual approaches refer to single technique without hybridize or integrate with other method. It is categorized into manual formulation, mathematical programming and stochastic programming. It is then followed by the proposed methodology for a feed mix problem. Finally, the conclusion and future work are presented.

II. Individual Approaches

A. Manual Formulation

1. Pearson's Square Method

Pearson's square method (PSM) shows the proportions of two feed ingredients to be mixed together in order to obtain the percentage of the particular nutrients [3], [21]. Due to this limitation, this technique is not possible to use in complex feed mix problem, and normally applied in balancing protein requirements only. On research conducted by [59] applied PSM in balancing corn and soybeans to meet 23% protein requirement. In this research, [59] tried to illustrate their work using a simple way to make people understand.

2. Simultaneous Algebraic Equations

An alternative method of pearson square is simultaneous algebraic equations (SAE) method which is be able to balance two or more feed ingredients to achieve optimal nutrients value [3], [21]. Nevertheless, this method can only balance for two nutrients at a time; hence it is not practical for solving a problem which takes many nutrients.

3. Trial and Error

Trial and error method (TAE) is the most popular method for feed formulation for poultry [3]. The formulation is done either manually on paper or by using computer spreadsheet such as Excel, Quattro Pro and Lotus123 [19]. However, to gain the optimal result this method required much time to spend especially when there are a lot of ingredients and nutrients need to be considered.

B. Mathematical Programming

1. Linear Programming

In farmed animal diet, [71] was the first researcher who attempted to solve the feed mix problem using mathematical programming. It happened when he figured out that linear programming (LP) method was best suited for solving animal diet problem. In his attempt, [71] honestly admitted that he was not an animal nutritionist, but trying to look for the suitable method to lighten the animal nutritionist job. Since then, LP is used widely in modelling the animal feed problem [4], [7], [9], [11], [13], [16], [22], [29], [34], [42], [43], [44], [46], [60], [63], [67], [68], [77]. The common objective in formulating the feed mix is to minimize cost while providing adequate nutrients to meet the needs of the farmed animal type being fed [13], [71].

However, due to various constraints that need to be considered, the feed mix problem has become increasingly difficult. Thus, using LP alone cannot overcome all of the problem complexities. The issues arisen in feed mix include:

1) nutrients level of feed ingredients is unstable and fluctuates [44], [47], also termed as ingredients variability;
2) prices of feed ingredients are not constant, can be termed as price variability;
3) nutrients imbalance occurs in the final solution; and
4) infeasible solution occurs.

In consequent, various type of methodologies have been proposed by researchers in this field such as goal programming (GP), multi goal programming (MGP), multi objective programming (MOP), multi objective fractional programming (MOFP), nonlinear programming (NLP), chance constrained programming (CCP), quadratic programming (QP), risk formulation (RF), and genetic algorithm (GA).

In the reputation of LP as a tool to find optimal solution in feed mix problem, some LP limitations have been identified. As found out by [41], there are three weaknesses in LP. The first weakness is that the LP models assume nutrients levels are fixed. However, nutrients levels in feed ingredient are unstable and fluctuating [44], [47]. In fact, when the variability among ingredients is neglected, the probability in meeting nutrient restriction is only 50% [48].

The second weakness is that the LP method is regularly hard to determine a good balance of nutrients in the final solution. If only the minimum levels of nutrient requirements are placed, there is a probability for nutrients imbalance to arise in the final solution. Balance nutrients and variability are related. Hence, when the variation is small, the quality of balance nutrients will improve [76].

The third weakness is the constraints rigidity in LP, which means that no constraints violation is allowed. This weakness will normally lead to infeasible solution [1], [43], [76].

Other than these weaknesses, there is one obvious LP characteristic which many researchers identified as another LP weakness. It is that LP models can handle only one objective function, normally the least cost rations [37], [54], [56], [76]. In addition, as a name appear; LP can only tackle for linear constraints. However, there are nonlinear constraints exist in the feed mix problem.

Besides the LP drawbacks highlighted here, however, as a deterministic approach, LP is the best method to apply in the feed mix problem if all the prices and nutritive values of feeds are known because LP will lead to the optimal solution. In addition, LP provides a solution to problem that requires solving hundreds of equations simultaneously [5].

2. Goal Programming

GP was at first used by [1] with the intention to ensure nutrients imbalance and solve infeasibility problem for human diet. In their research, [1] showed the differences in using GP as compared to LP. The results showed improvement in using GP in terms of nutrient imbalance. Due to consideration of another objective, [54] used the GP technique, which considered minimizing cost, nutrient imbalance and the bulk intake by the animal. Later, [55] used GP when considering the nutritional requirements as constraints which may or may not be achieved, instead of fixing the value for minimum and maximum level of nutrient requirements. They also added in penalty functions into weighted goal programming (WGP) as a way to overcome the strictness of the constraint set in the LP formulation, which is the third LP weakness.

3. Multi Goal Programming

[37] used the same idea as [55] but applied MGP model and introduced the relaxation of nutrient requirements constraints since some relaxation of the constraint would not seriously affect the animal economic performance. Subsequently, [38] extended their work since the relaxation of constraints procedure could severely reduce the ration cost. [38] successfully minimizes the deviations from the nutritional requirement goal; hence, producing diet that satisfies the minimum nutritional imbalance. In a study, [76] considered two objectives, which are minimizing the cost and minimizing the nutrient variability for protein, methionine and lysine.

MGP apply the same concept with GP but difference in terms of modelling the objective separately. Based on previous work, both GP and MGP have an advantage to handle multiple objectives simultaneously, including nutrients variability and reducing the nutrients imbalance problems. Unfortunately, none of the research proved that GP and MGP techniques can overcome the problem of price variability.

4. Multiple Objectives Programming

[36] has proven that MOP technique provides a good solution in terms of balancing nutrients. [41] applied interactive MOP method with the same objective to solve the nutritional imbalance problem in feed mix. Using satisfying trade-off method (STOM), they fruitfully measured nutritional requirements as a constraint with the upper value being adjustable. STOM actually improves the method proposed by [38] and provides alternative solution to nutritional imbalance problems.

[70] observed the possibility to use a nonlinear MOP in order to consider three objectives, which are to minimize cost; minimize nitrogen excretion and minimize phosphorus excretion from dairy cows. The researchers experimented with two approaches, i.e. model each objective separately and simultaneously. In conclusion, it is acceptable to model each objective separately for a complex problem, but of course simultaneous approach will provide better solutions.

In agreement with previous researcher, [6] explored MOP techniques with the intention to reduce cost and nitrogen excretion simultaneously in pig's diets. [6] modified LP algorithm so that both objectives can be accounted for. This is a good attempt, but the difficulty occurred, which is with a little increase of feed cost, the nitrogen excretion will be affected seriously. Due to the difficulties in [6], the same algorithm has been altered by [50] with the objective of minimizing phosphorus excretion. [50] profitably shown that the adequate level of phosphorus decreases when the feed cost increases.

5. Multi Objectives Fractional Programming

MOFP model was developed by [36] to allow for both fractional and linear objective functions. Since [36] conducted the research using MOP and MOFP, [36] concluded the proposed model with fractional objective yielding better solutions to the specific situation. Having same concept with [36], [10] then considered more than least cost objective, which includes environmental factors. The factors included were minimizing maximum deviation with the aim to get ideal protein composition and phosphorus minimization. The researchers also take into account the ratio between lysine and energy constraints, which is in fractional value. The advantage of this approach is in enabling the decision maker to consider fractional objectives in the model hence, providing wider variety of application [35]. The core advantage of MOP and MOFP methods is to ensure optimum nutrients imbalance. However, the price variability is ignored and still cannot be solved.

6. Nonlinear Programming

Instead of looking into the variability in the feed ingredient, [25] examined the variation of broiler price. NLP method was used to tackle nonlinear constraints. This method gives an advantage to user because it considers real world problem by taking into account the variation of factors. In this study, the author has proven that broiler price should be taken into consideration as one of the factor in feed mix model development.

C. Stochastic Approach

1. Chance Constrained Programming

CCP is a nonlinear approach to feed formulation [60]. CCP is formulated when a deterministic problem occurred in which some of the parameters are not constant [52]. With the assumption that the nutrients in the ingredients are not deterministic, [47] is one of the pioneer researchers who used stochastic approaches. [53] continued with the work of [47] and successfully proved that the variability among sample mean can be accounted for and measured by variances.

Both results show that nutrients variability problem could be solved if compared to LP. This approach showed that the probability of the nutritional requirements will be met in [47] and [53] research has shown an increase from 50% to 95% and 80% respectively. By comparing LP and CCP, the CCP shows that the probability that nutritional requirements will be met increases from 60% up to 90% [59]. However, in [53], the solution for iteration requires a trial and error method which of course is time consuming.

On the other hand, [58] used CCP technique focusing on amino acid value. In this study, the variability among ten selected amino acids was calculated based on mean and standard deviation of the digestibility values. Knowing the advantage of CCP in terms of variability, [63] cater the ingredients and price variation problem using this technique.

In a different condition, by using solver tool in Excel spreadsheet, [48] solved linear and nonlinear problems arise in feed mix problem. Furthermore, another advantage of their spreadsheet is that it considers stochastic side of nutrient's ingredients. The spreadsheet is similar to [53] algorithm. Therefore they choose the same probability of having required protein level in this feed, which is also 80%. This spreadsheet provides the ability to edit the objective function and constraints, such as ingredient feed, nutrients ratios, and nutrients limit.

In conclusion, CCP is a better approach as compared to LP especially in solving nutrients variability, which is the LP disadvantage. Additionally, [60] concluded that CCP's advantages are minimizing cost and the variability of nutrients is accounted for in the formulation.

2. Quadratic Programming

[14] proposed QP to maximize the probability of meeting the nutrient requirement. In this research, [14] chose the minimum ration cost from a series of ration that satisfied all constraints. However, the author stated that the QP codes available at that time were not efficient for large problems.

3. Risk Formulation

Reference [69] proposed the risk formulation (RF) model as an alternative way to capture variability problems. Because of the successful work by [38], their model was adapted with the objective to minimize nutritional imbalance. Finally, the researcher compares the proposed model with that of CCP. The result shows that in terms of variability, the risk formulation is well suited with the CCP, but more appropriate in the condition of having high ingredient price variation. The research successfully considers many issues addressed in the feed mix problem. However, the researcher concludes that for the nutritional imbalance problem, the modified model has a big drawback of acquiring appropriate weights and thus, becomes very complex.

4. Genetic Algorithm

In 1997, [20] solved the nonlinear constraints in feed mix problem using genetic algorithm (GA). The nonlinear constraints involved the ratio of ingredients. In this research, [20] ignored the other issues arise in feed mix problem. More recently, [61] discovered the use of GA to develop the feed mix model. [61] major concerned was to achieve zero penalty function. Their GA experiments produce great solution for a problem with a few constraints. However, [61] faced difficulty in problems with many constraints due to results with zero penalties could not be obtained. Penalty value exists when the desirable limits are violated [38]. Commonly, this problem arises when the nutrient requirement's constraints are set as goals, which may or may not be achieved. The goals could be satisfied fully, partly, or most of them might be not met [74]. One advantage of GA approach is the opportunity of achieving feasible region is increased. More information on penalty function in feed mix can be viewed in [38], [55], [57] and [74].

The major advantage of GA is its effectiveness in finding the best-so-far feasible solution by exploring various parts of the feasible region [27]. Other than that, GA can handle multiple objectives and also provides a compatible framework that is easy to combine with other methods including optimization techniques [18], [64].

III. Integrated Approaches

A. Integrated LP and DP

[23] build up a model to join together crop and livestock production. In this research, [23] begins by using Dynamic Programming (DP) model to get the minimal cost while increasing animal weight. Then, [23] used the results from DP to find the coefficients of the feeding activities by using LP model. For the reason that importance in lactation period for dairy cows, [49] used LP model to minimize total cost of feed ingredients. DP then was used to determine the optimal series of weight changes for the whole lactation period and also the ration used to obtain the optimal value. As a conclusion, this approach is appropriate while determine the optimal ration in the condition of involving phase.

B. Integrated LP and Fuzzy

Believe with the concept of there is impossible to have a perfect knowledge of all or some of the data, [8] discover the application of fuzzy concept in feed mix problem. Fuzzy elements including constraints, objective or coefficients then integrate with LP model to obtain fuzzy linear programming model. This model then solved using decision support system which was developed earlier by the researchers. This approach is one of the superior contributions towards feed mix area that is having a great potential to further investigate.

C. Integrated LP and WGP

[73], [74] and [75] combined LP and weighted GP (WGP) in order to produce optimal ration cost with balance nutritional requirement. Primary concerns of these papers were to overcome some LP drawback such as LP rigidity and single objective function in LP. In this study, [73], [74] and [75] applied the same concept introduced by [54] which incorporating penalty functions. These studies fruitfully reduced nutritional imbalance problem.

D. Integrated GA and Fuzzy

[17] recommended of combining GA in fuzzy optimization method to provide more advantages towards optimization problems such as less iteration and small chance of being trapped into premature states. The advantage of this theory is able to tackle linear and nonlinear problems. However, due to the core objective of their study is on theory, [17] do not considered all feed mix issues.

E. Integrated GA and Monte Carlo Simulation

In intention for solving CCP problems in many field [51] developed a method based GA with Monte Carlo Simulation (MCS). In the field of feed mix, the researchers compare their work with [47] and found out that their solution was better. This research was not taking into consideration for the issues in feed mix area. Tables I and II summarize the works in the feed mix problems that have been done.

TABLE I
SUMMARY OF INDIVIDUAL APPROACHES APPLIED IN THE FEED MIX PROBLEM

Method	Sources
PSM	[3], [21], [59]
SAE	[3], [21]
TAE	[3], [19]
LP	[4], [7], [9], [11], [13], [16], [22], [29], [34], [42], [43], [44], [46], [60], [63], [67], [68], [7 [77]
GP	[54], [55], [57]
MGP	[37], [38], [69], [76]
MOP	[6], [36], [41], [50], [70]
MOFP	[10], [36]
NLP	[25]
CCP	[47], [48], [53], [58], [59], [60], [63], [69]
QP	[14]
GA	[20], [61]
RF	[69]

TABLE II
SUMMARY OF INTEGRATED APPROACHES APPLIED IN THE FEED MIX PROBLEM

Method	Sources
LP and DP	[23], [49]
LP and Fuzzy	[8]
LP and WGP	[73], [74], [75]
GA and Fuzzy	[17]
GA and MCS	[51]

IV. THE PROPOSED METHODOLOGY

Based on the discussion early on, in the feed mix problem, individual approach is more popular than integrated approach. In fact, as found in the previous sections, most of the integrated methods were done either to enhance the theory of technique used or to introduce new idea in feed mix problem. In this study, we propose the application of GA [24], [28] which is successfully applied to real world problems [40] including nonlinear problem, discrete, continuous or mixed search spaces, constrained and unconstrained [64]. GA is expected to deal with all of the issues in the feed mix since GA is able to cater for multiple objectives. Another advantage of GA is the stochastic approach which is a must to deal with stochastic environment.

Furthermore, based on other GA advantages mentioned in the previous section, the methodology of GA is deemed suitable to tackle the feed mix problem. GA is expected to achieve the main objective of the problem, which is to obtain the minimum cost diet for farmed animal, while satisfying nutritional requirements. As explained in previous section, up till now there are a few papers have been done using GA in the feed mix area; however, the focus of each paper is differs. Apparently, the aim of this study is to continue [61] work which is to get no penalty value solutions. At the same time, we want to consider all the feed mix issues addressed earlier. However, as mentioned in previous section, [61] hard work using GA alone could not overcome the penalty problem arise in problems with many constraints. In consequences, we decided to integrate GA with other Artificial Intelligence techniques that come from bees' family.

In Fig. 1, we proposed a framework to hybrid GA with Artificial Bee Algorithm. This algorithm is believed to obtain feasible solution since this algorithm combines local search method with global search method. In this algorithm, two types of Artificial Bee Algorithm are considered; Artificial Bee Colony (ABC) algorithm and Marriage in Honey Bee Optimization (MBO) algorithm. ABC algorithm was originally proposed by [32] in 2005 for numerical optimization. This algorithm is actively shaped by [32] and its colleagues in recent times. ABC framework is chosen here to increase the exploration and exploitation in basic GA algorithm. Exploration will generate additional diversity while exploitation creates better solution [66]. Apparently, MBO algorithm was initially proposed by [2] and then the algorithm was enhanced by other researchers including [12]. In our algorithm, we adopted a step introduced by [12] which is similar to Simulated Annealing (SA), though the different is the cycle will be done exactly once at a time. In the MBO analogy, this process is done once for each speed with the control of the sperm contents of queen spermatheca by keeping only the best drones generated until the queen's energy gets worn out [12]. However, SA is inspired by an analogy of physical annealing process of solids to obtain low energy states. Since MBO is similar with SA, thus its major advantage is on taking steps in random directions in order to explore as much of the feasible region as possible. Since this procedure takes only one cycle, the process will not takes for a long time as SA does. Thus, by incorporating GA, ABC and MBO, this algorithm is expected to produce great solution for feed mix problem.

To best of our knowledge, so far only one paper has been integrating GA with ABC algorithm written by [26]. In this work the researchers incorporating quantum EA that come from the principle of quantum computing. Quantum refers to the smallest of all places that is the subatomic particles that form the basis [26]. Their algorithm is similar with GA, however after mutation they include one step; apply quantum whole interference crossover which is useful to avoid premature convergence and stagnation problems. On the other

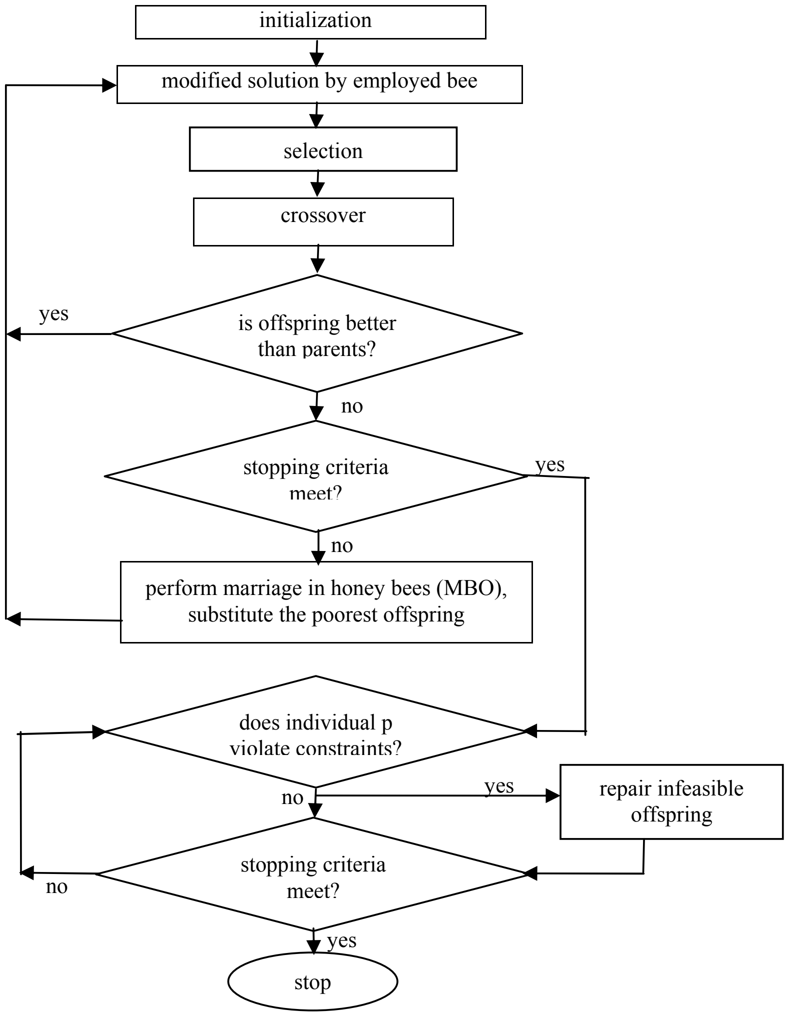

Fig. 1 Modelling approach of cost optimization of the feed mix using GA incorporating Artificial Bee Algorithm

hand, in our algorithm, we employ the ABC framework and adopt with GA to acquire the advantage of both techniques. Thus, in the proposed algorithm, we include several things which differ from simple GA (SGA). There are:

i. Local search is included before selection procedure is made.
ii. Offspring checking is introduced after the crossover procedure.
iii. Repair algorithm is operating if the infeasible solutions exist.

Basically, this algorithm begins with initialization of random population. Then, this solution is modified by employed bee. In this algorithm, employed bee represented the local search procedure. In the first matter, the aim of inserting local search in early stage is to improve the offspring value as well as to speed up the convergence of the algorithm. This approach have been discussed by [15] and [62] which agreed that incorporating local search can accelerate the search towards global optimum thus will lead to a better convergence rate. The better solution then will be updated and replaced the old one. After that, Roulette Wheel Selection is take place. In ABC algorithm, the solution which is known as food sources will be chosen with a probability based on the nectar amounts. The nectar amount of a food source corresponds to the quality of the solution represented by that food source [33]. Thus, the higher nectar amount has the higher chances to be chosen. The crossover procedure will be carried out to modify the solution once more time and the better solution will be updated.

In the second matter, a crucial idea here is the introduction of checking operator and MBO algorithm to substitute mutation. After crossover procedure end, the checking operator will check the offspring either it is better or worse than its parents. If the offspring is worse than its parents and the stopping condition is meet, the checking operator will check the solution either it is feasible or not. If the solution is feasible, then the program will stop. For the case that the solution is still can improve, MBO algorithm is operated. In SGA, the purpose of mutation is to avoid local minima by preventing the population of chromosomes become too similar to each other. The mutation operation task is to generate offspring by randomly changing one or several genes in an individual. Offspring may thus possess different characteristics from their parents. However, if the offspring is worst than its parents, there are a waste to make other improvement to the offspring. The better way is to find other new solution and try to improve the solution thus increase more chances to obtain global optimum since the MBO explores the search space more thoroughly. The process to find other solution can accidentally discover high-quality solution [33]. This process will be done until stopping criteria meet. This study will be using stopping criteria as suggested by [31] based on best and worst point.

Thirdly, if the solution is not feasible or penalty values still exist, a repair operator is operate to reduce the penalty function value. The most recent review paper in this sense is conducted by [62]. By reviewing 137 papers, the researcher concluded hybrid approaches with repair heuristics obtain better results compared to other constraint handling techniques. Repair operator's task is to fix some chromosomes with replication or absents of genes [72]. Recent work by [72] proves that the application of this operator can successfully reduce the penalty function value in timetabling problem. To our knowledge, there is no study which adapts this technique in the problem of feed mix.

Several studies which applied penalty function in feed mix (e.g. [38], [55], [57], [74] are concerned more with the benefit of the penalty function in obtaining feasible solution rather than how to obtain the solution without penalties. This motivates the investigation of this approach in solving the feed mix problem with the aim of improving the solution.

In developing the feed mix model, some data on farmed animal such as shrimp could be utilized. The dataset would be obtained from records on feed composition, literature reviews and interviews with expertise in shrimp nutrition. It is hoped that various possible ingredients could be included in our study (e.g. based on The Canadian Tables of Feed Composition and Malaysian ingredients by [30] in order to achieve low ingredients price rate.

V. CONCLUSION AND FUTURE RESEARCH

This paper describes the preliminary stage of our ongoing research work thus much more work is needed. Feed mix model with specific constraints must be determined precisely to become the base for programming development. Then, once the model is build up, a comparison with existing shrimp feed endorsed by Department of Fisheries (DOF) Malaysia will be done to evaluate the solutions of our proposed method. It is hoped that a GA based with integrated artificial bee algorithm is able to fulfil all the issues highlighted in the problem of feed mix.

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