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A GLNPSO for multi-level capacitated lot-sizing and scheduling problem in the poultry industry

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ABSTRACT

This paper presents a computation tool for the multi-level capacitated lot-sizing and scheduling problem in hen egg production planning with the aim of minimizing the total cost. A mixed-integer programming model was developed to solve small-size problems. For large-size problems, particle swarm optimization (PSO) was firstly applied. However, the component of traditional PSO for social learning behavior includes only personal and global best positions. Therefore, a variant of PSO such as the particle swarm optimization with combined gbest, lbest and nbest social structures (GLNPSO) which considers multiple social learning terms was proposed. The local search procedure was applied to decide the new sequence of chick and pullet allocation to rapidly converge to a better solution. Moreover, the re-initialization and the re-order strategy were used to improve the possibility of finding an optimal solution in the search space. To test the performance of the algorithm, the two criteria used to measure and evaluate the effectiveness of the proposed algorithm were the performance of the heuristic algorithm (*P*) obtained by comparing their solutions to optimal solutions, and the relative improvement of the solution (*RI*) obtained by the firm's current practice with respect to those of traditional PSO and the GLNPSO algorithms. The results demonstrate that the GLNPSO is not only useful for reducing cost compared to the traditional PSO, but also for efficient management of the poultry production system. Furthermore, the method used in this research should prove beneficial to other similar agro-food industries in Thailand and around the world.

1. Introduction

In the egg industry, egg production planning is considered a crucial activity because it may affect production costs. Since egg production planning concerns not only the number of chicks required over a period of time, but also how to allocate chicks to replace birds with diminishing laying capacity, egg production requires efficient planning for minimizing costs in order to maximize profit generation while meeting the customer demand. Moreover, egg production is considered a dynamic system leading to complex production, especially the chick ordering and the decision of how to allocate flocks to facilities. Allocation of flocks to facilities in the current period may affect the efficiency of allocation of the flocks in the next period. The main challenges for the firms when determining the lot size of chicks and allocating them to houses are due to the following production complexities, (1) The egg industry is a hierarchical multi-level production starting from purchasing chicks from a hatchery on a weekly basis and delivering them to the pullet-raising farms where the chicks stay until they are 17 weeks old, then transferring pullets to egg laying units (hen houses) where they are fed to have sufficient body weight to support egg production, and remain there until the age of 75 weeks. Once the hens are no longer valuable as layers, they are moved to be slaughtered at the firm's slaughter house. Hence, the number of chicks required depends on the customer demand (i.e. eggs), pullets on hand, layers on hand, egg production rate of hens and survival rate of both hens and pullets. Chick ordering is considered as medium term planning with hens to be determined before allocating pullets to hen houses (see Fig. 1). (2) There are numerous houses with limited and heterogeneous capacities. Due to an imbalance between the flow-in flocks and the capacity of the facilities, this challenges the firm attempting to allocate flocks to the facility as fully as possible, because a facility with partial fill of pullets or hens may lead to high production costs. Hence, the capacitated lot sizing problem is very important in managing chick ordering and considered as short term planning (see Fig. 2). (3) Even though the number of chicks required depends on the crucial factors mentioned earlier, the maximum ordering quantity of chicks must not exceed the maximum daily capacity of the firm's slaughter house. Thus, an egg industry should have an efficient method to make a balance between the customers' demand and the decision of how many chicks to purchase and

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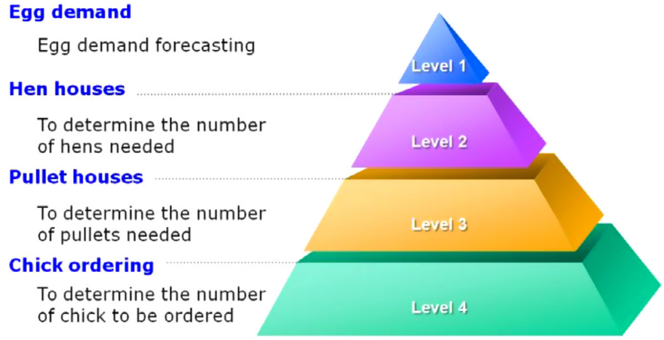

Fig. 1. Hierarchy production planning in the Poultry industry.

deliver to the industry in each time period, while the maximum number of chickens ordered in each period is restricted. However, it can be difficult and complex to combine lot sizing and scheduling problems as they are interdependent. As a result, they are often modeled and solved independently, which may lead to not obtaining globally optimal solutions (Mahdieh, Bijari, & Clark, 2011).

This paper therefore focuses on the multi-level capacitated lot sizing and scheduling problem for egg production with a restriction of the maximum lot size at each time. The objective of this research is to minimize the total costs consisting of chick ordering cost, feed cost of pullets and hens, farm utilization cost, egg storage cost, hen transportation cost from pullet houses to hen houses, and demand shortage costs. To solve the problem, interrelationships existing between the chick ordering level and chick allocation to house level are considered and taken in the model simultaneously in order to obtain globally optimal solutions. An efficient mixed integer programming model was developed for small-size problems. Since the problem considered is an NP-hard problem, the computational effort, in general, required to find an optimal solution grows exponentially with the size of the problem. In an effort to find a near optimal solution for problems with larger, more practical problems, a meta-heuristic was developed. A well-known meta-heuristic called Particle Swarm Optimization (PSO) is brought to develop an efficient algorithm.

PSO is a population based search method which was motivated by group organism behavior such as bee swarms, fish schools, and bird flocks (Kennedy & Eberhart, 1995). It imitates the physical movements of the individuals in the swarm as a search method, altogether with its cognitive and social behavior local and global exploration abilities. Hence, in this paper, the PSO algorithm is firstly applied for the purpose. However, the component of traditional PSO for social learning behavior includes only personal and global best positions. Therefore, a variant of PSO such the particle swarm optimization with combined gbest, lbest and nbest social structures (GLNPSO) developed by Pongchairerks and Kachitvichyanukul (2005, 2006) was proposed in this paper which considers multiple social learning terms including personal, global, local, and near neighbor best positions. The local search procedure is applied to decide the new sequence of chicks and hens allocated in each time period to rapidly converge to the better solution. In order to avoid being trapped into a local optimum, the re-initialization and the re-order strategy are used to improve the possibility of finding an optimal solution in the searching space. To illustrate the proposed method effectiveness, numerical experimental results were compared with the mathematical model, the current practice of the egg industry selected as a case study and also with the traditional PSO. In the next section, related literature is reviewed. In Section 3, we present the hen egg production formulation. In Section 4, we provide a comprehensive detail of our solution procedures. In Section 5, the case study application and an outline of experimental results are presented. Finally, a summary of the main findings is given in Section 6.

2. Literature review

Multi-level production lot sizing and scheduling are the most important tasks to fulfill in a manufacturing system, because they have a strong impact on its performance and productivity in terms of operating costs, machine utilization, and customer service quality. A manufacturer must make decisions about these two problems hierarchically and integrally. Due to their dependency, this problem is also called the general lot-sizing and scheduling problem (GLSP), which considers lot-sizing and scheduling simultaneously. Generally, the lot-sizing model is first determined (Karimi, Fatemi Ghomi, & Wilson, 2003; Toledo & Armentano, 2006; Ramezanian, Saidi-Mehrabad, & Fattahi, 2013), then the output from this model will be an input to incorporate the sequences of lots, which involves the determination of when each lot is produced on which machine or production resource. The multi-level lot-sizing and scheduling problems can be very complex and difficult tasks depending on the precedence constraints which have to be satisfied and on the multi-level structure (Toledo, de Oliveira, & Franca, 2013). Generally, they are classified as NP-hard optimization problems (Stockmeyer & Meyer, 2002).

The reviews of Drexl and Kimms (1997), Jans and Degraeve (2008), and Clark, Almada-Lobo, and Almeder (2011) show that the field of lot sizing and scheduling has caught the attention of researchers in order to solve real world problems. Historically, the economic order quantity (EOQ) is well known and popularly applied to determine lot-sizing that balances the setup cost and the inventory holding cost (Harris, 1913; Wilson, 1934). A few decades later, Wagner and Whitin (1958) presented a dynamic programming algorithm for the single-item uncapacitated lot-sizing problem, which provides its optimal solution. More recent work by van Hoesel and Wagelmans (2001) provided a theoretical underpinning for fully polynomial

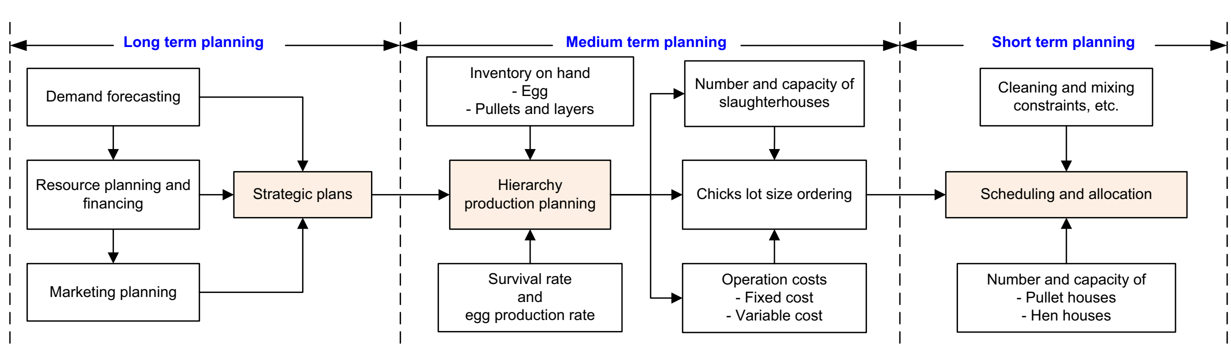

Fig. 2. Hen egg production planning.