FUZZY LINEAR PROGRAMMING MODEL OF ANIMAL FEEDS RAW MATERIAL PROCUREMENT PROBLEM TO STUDY THE IMPACTS OF GOVERNMENT POLICIES

BY

MS. NGUYEN NGOC AI THY

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING (LOGISTICS AND SUPPLY CHAIN SYSTEMS ENGINEERING)
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ABSTRACT

This paper involves a raw material sourcing problem the feed industry in Thailand from the perspective of a government policy maker. The problem focuses on determining optimal raw material sourcing decision, including purchase and usage amounts of domestic and imported raw materials to satisfy demands of major feeds from livestock industry. Domestic raw materials considered are maize, by-products of rice, cassava chips, fish meals, rice bran oil, and imported raw materials are soybean meal, wheat grain, and DDGS. Three major feeds in Thailand include broiler, hen, and swine feeds, which are separated into eight types according to animal growth stages. Two main nutrient requirements, protein and energy, are considered. Key system measures include the total cost of raw materials, average feed cost, and remaining domestic raw materials at the end of the season. The problem arises for the policy maker because cheaper imported raw materials can satisfy the energy requirement. This directly impacts domestic raw material usage and Thai farmer incomes. A fuzzy linear programming model that minimizes the imprecise total cost under uncertain data, is formulated. Constraints representing the current government policies on imported raw materials and storage capacity are incorporated to estimate the policy impacts. The results suggest an appropriate policy that leads to a reasonable tradeoff between potential loss in competitiveness of the feed industry and the domestic farmer benefits.

Keywords: feed raw material sourcing, government policies, storage capacity, fuzzy linear programming, triangular fuzzy numbers, cost optimization

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CHAPTER 1

INTRODUCTION

1.1 Research background

Food industry in Thailand is growing due to export and domestic demands of value-added food products and services, e.g. ready meal, frozen food, chilled food. In 2017, the total food production is approximately 34.98 million metric tons, a 5.61 percent increase from the previous year. Domestic demand is 20.70 million metric tons, an increase of 3.99 percent from 2016, and the value of export demand is 28.96 billion USD, a yearly increase of 10.72 percent (The Office of Industrial Economics, 2020). Major food and agricultural product exports include rice, rubber, fruit (mostly canned pineapple), fishes (mostly canned tuna), cassava products, sugar, broiler meat, and shrimps. Among them, broiler meat and related products rank 7th in terms of Thailand export value (Global Agricultural Information Network report, 2018), with an annual growth rate of 9.71 percent in 2017 (IndexMundi, 2018). From 2016 to 2019, total food production increased by 1.35% because the total food domestic consumption increased by 6.6%, and the amount of food export increased by 1.16%. An increase in domestic food consumption led to the growth in feed domestic consumption, which increased by 8.83% during 2016-2019. Moreover, the amount of feed export rose 2.57% from 2016 to 2019, thus, the total feed production increased by 7.35% during this period. According to the increase in food consumption and feed demand over the past four years, the total sale from food products and feeds grew by 4.43% and 8.82%, respectively. As a result, the total value of food sales reached 9,495,510 USD (300,817,755 THB) at the end of 2019, increased by 2.98% compared to 2016. Because of the significant growth in the total feed domestic sale compared to 2016 (8.83%), the total value of feed sale had risen 6.05% in 2019, achieved at 4,892,252 USD in this year.

In this value chain, the food industry has the livestock industry as a direct upstream stage, which in turn has the feed industry as its upstream stage. The growth in food industry, therefore, leads to the growth in the feed industry. According to Thai Feed Mill Association (2018), the total feed demand is expected to increase to 20.1

million metric tons in 2018, up slightly (2.6 percent) from 2017. Among all major livestock, the top three are broiler, swine, and hen, which account for 77.2 percent of all livestock production in 2018. Broiler production, which represents approximately 32.5 percent of the total feed demand is expected to increase by 2.4 percent from 2017, as broiler meat exports will likely remain strong. Swine production, which makes up another 28.2 percent of total feed demand, is expected to increase by 5.2 percent from 2017. This increase is mostly from domestic consumption, while there is a slight decline in swine exports to China. Additionally, hen production, approximately 16.4 percent of the total feed demand, is expected to slightly decline by 1.4 percent from 2017.

Producing feeds involves many domestic and imported raw materials (RMs). On the supply side, domestic RM supplies are limited and vary according to their harvest seasons, while the import RMs are readily available. These RMs are different in terms of their prices, the nutrient they provide to feeds for different livestock. Some RMs can be used as replacement of another RM when the price is more competitive, given that they provide relatively the same nutrient. For example, either domestic maize or imported wheat grain can be used as a major RM that satisfy energy requirement of a broiler feed. On the demand side, feed demands are expressed in terms of the total amount, i.e. million metric tons, and nutrient requirements. Important nutrient requirements of feed demand include protein, energy, and micronutrient supplementation such as mineral, vitamin, etc. Also, nutrient requirements of feeds are different based on the types of livestock and stages of growth.

The cost of RMs is the highest proportion, 70-75 percent, of the total feed production cost (Sahman et al., 2009). One of the most important tasks for feed manufacturers is to find a feed formulation that specifies the type and percentage of RMs to be mixed together to satisfy feed demand (amount and nutrient requirements) with the total minimal cost. In order to reduce RM cost, feed manufacturers tend to use the most cost effective RMs available. In Thailand, the cost of RMs that are produced domestically are not as competitive as the cost of imported RMs. As a result, the feed manufacturers are using less domestic RMs and importing more RMs from overseas. This created problem for more than one million of Thai farmers, who could not sell their harvest to the feed manufacturers. As this trend continued to impact Thai farmers, the Thai government agency that is responsible for internal trades needed to make some policies to help Thai farmers without incurring much losses in the competitiveness of food, livestock, and feed industries.

1.2 Problem statement

In Thailand, the cost of RMs that are produced domestically is not as competitive as the cost of imported RMs. As a result, the feed manufacturers are using less domestic RMs and importing more RMs from overseas. This created problem for millions of Thai farmers, who cannot sell their harvest to the feed manufacturers, i.e. RMs cost of maize (domestic source) is higher than wheat grain (imported source), the price of maize is from 8.7 to 10.5 THB/kg (2018-2019), compared to wheat grain which ranges from 7.4 to 8.5 THB/kg (2018-2019), and Thai farmers stock up million tons of maize. As this trend continues to impact Thai farmers, the Thai government agency that is responsible for internal trades need to make some policies to help Thai farmers without jeopardizing the competitiveness of food, livestock, and feed industries.

In this study, a similar approach to finding an optimal feed formulation for a manufacturer is implemented, but with a difference that the problem is solved from the perspective of the policy maker. That is, the study aims to investigate the impacts of government policies on the cost of matching supplies (RMs) and demand of major feeds for the whole industry, while considering macro aspects of the system. In other words, the problem under study focuses on raw material sourcing decisions, rather than finding optimal feed formulation for a particular manufacturer. Specifically, the problem considers (1) feeds for three major livestock: broiler, hen, and swine; (2) important domestic RMs that have to compete with cheaper imported RMs; (3) two major types of nutrient requirements, protein and energy, and (4) two additional constraints of the systems, which are government policy and RM storage capacity. The objective is to minimize the total cost of RM purchase, preprocessing, and inventory holding, while satisfying not only the demand, but also the government policy and the storage capacity constraints. Key decisions are to determine optimal monthly purchase and usage amounts of RMs for major feed production in Thailand with a planning horizon of 12 months. Important system measures of performance are the total cost, average feed cost, and the remaining amount of domestic RMs at the end of the planning horizon.

The paper presents a fuzzy linear programming (FLP) model formulation that captures the common characteristics of the feed mix problem as well as other important aspects, including government policies and storage capacity, from the policy maker point of views, and fuzziness in important model parameters are considered to investigate impacts of uncertainty. The models give estimates of the policy impacts on the system measure of performance. The results can suggest an appropriate policy that leads to a reasonable tradeoff between benefit gained by Thai farmers and financial loss of the feed industry under uncertainty.

1.3 Research objective

The research objectives are summarized as follows:

- Considers feed demand, supply availability, and two major nutrient requirements including energy and protein.
- Collect crucial data in recent years and as many as possible to determine their value fluctuations.
- Model the imprecise data using the triangular possibility distribution.
- Develop a mathematical model to minimize the total cost of purchasing and preprocessing RMs, and inventory cost.
- Balance the main RM supplies (domestic and imported source) with feed demand for the whole industry.
- Determine the optimal purchase and usage amount of each RM for chicken and swine feed production under uncertainty
- Investigate the impacts of government policies on the cost of matching RM supplies and feed demand for the whole industry.

1.4 Overview of the research

The remaining contents of this research are summarized in the section below. Chapter 2 contains a literature review that provides a synopsis of the characteristics and contributions of previous relevant research studies, helping to define the research gap our study aims to fill. Chapter 3 provides a comprehensive description of problems, the characteristics of problems, government policies, and assumptions. Next, Chapter 4 demonstrates a description of input data and the FLP model. Chapter 5 then gives results and discussions, as well as analysis of the scenarios. Finally, Chapter 6 sets forth conclusions and recommendations.

CHAPTER 2
LITERATURE REVIEW

2.1 Problem characteristics

The problem under study is similar to an optimization problem referred to as the feed mix problem or feed blending problem. In general, the feed mix (or blending) problem involves finding optimal feed formulation(s) with respective to one or more objective functions, while satisfying a set of feed mix constraints. The problem has been studied over the past few decades because of its importance to livestock feed production. Problem settings of relevant previous studies to our paper are categorized using the following characteristics: (1) scope of the problem, which is defined by the number of feeds, the number of RMs or ingredients, the number of nutrients, and the number of periods that are considered, (2) objective function, e.g. total cost minimization, profit maximization, and environmental factor related measures, (3) constraints, which may be one or more of the following, nutrient requirements (types of nutrients, the minimum and/or maximum percentage of RMs or ingredients), demand, and supply availability, and (4) modeling approaches, which vary in terms of the number of objective function (single or multiple), linear or non-linear model, and deterministic or stochastics (or fuzzy) models.

For the scope of the problem, most studies considered one feed at a time. Exceptions are such as Altun et al. (2015), which solved the problem for sheep, cattle, and rabbit feeds that share the same supplies of RMs; and our paper, which considers eight feed formulations for three livestock, all of which are sharing domestic RMs supplies. Since a livestock requires different nutrient requirements at different stages of growth, the total feed demand for the livestock is appropriately allocated to different feed formulations according to the animal lifespan in each stage of growth. Among the reviewed papers, the number of RMs (or ingredients) range from three to 75, and the number of nutrients range from two to 18. Our paper considers seven major RMs that are competing as sources of two main nutrients (protein and energy) for animal growth, and two generic RMs for buffer source of nutrients to ensure the problem feasibility.

For the number of periods, Jean dit Bailleul et al. (2001), Pomar et al. (2007), Pathumnakul et al. (2009), and our paper consider the problem in multiple periods.

Most studies aimed at finding an optimal feed formulation that minimizes the total cost, except Chagwiza et al. (2016), which focused on profit maximization. Among them, Tozer and stokes (2001), Castrodeza et al. (2005), and Jean dit Bailleul et al. (2001) considered multi-objective problems with additional objectives involving some environmental factor measures. Regarding the constraints, all studies consider feed demand that must be satisfied. Two studies, Altun et al., 2015, and our paper, consider more than one type of feed sharing common RMs, and therefore, include the RM supply availability constraints. For nutrients, most studies include both macro-nutrient (protein and energy) and one or more of micro-nutrients (e.g. vitamin, mineral, chemical), except Jean dit Bailleul et al. (2001) and our paper that only consider the macro-nutrient. This is because most studies focused on finding optimal feed formulation(s) for one manufacturer, while our paper focuses on the RM sourcing decisions for the feed industry. Other important constraints considered in some studies are the minimum and maximum percentage of RMs requirement for each feed. These constraints are also considered in our paper based on the recommendations from the major feed manufacturers in Thailand.

Widely used modeling approaches to solving the feed mix problems include deterministic models, i.e. linear programming (LP), non-linear programming (NLP), mixed integer linear programming (MILP), multi-objective programming (MOP); stochastic (or fuzzy) models, i.e. stochastic programming, fuzzy optimization models; and heuristic approaches, e.g. bat algorithm, genetic algorithm.

Herrera et al. (2015) developed a linear programming model to analyze the feeding basis in a tropical dairy farm. Decisions are the amount of land area to plant each of the forage species that are mixed in the cow feed. Important constraints, in addition to nutrition requirements, are budget limitation and total land area limitation. The objective function is to maximize the dry matter production. A sensitivity analysis is performed and the results indicate that the optimal solution is robust to model parameters. Munford et al. (1996) formulated two non-linear optimization problems arising in animal feed formulation as an iterative linear programming problems. The first objective is to meet the nutrient requirements in the complete diet problem for dairy cows, and the second objective is to formulate batches of the feed with nutrient variability. The study solved these problems using a model called, the Ultramix feed formulation and modelling system. Stokes and Tozer (2006) developed a non-linear programming (NLP) model for a feed blending problem to minimize the cost of raw ingredients, with nutrient requirements of pellets. Empirical application of the model is made to broiler feed, and the results are better from those determined by the common sequential LP approach.

In practice, feed producers usually have to handle many competing objectives to formulate rations. An important objective, in addition to minimizing feed cost or maximizing profit, is to reduce the nutrient excretion. The most common approach to solve more two or more objective functions simultaneously is multiple objective programming (MOP), multi-objective goal programming, interactive multiple goal programming (IMGP), and compromise programming. Many studies have used MOP as an efficient tool to assist the decision-making process to be more flexible in providing a compromise solution than a traditional feed formulation with a linear/non-linear programming. Tozer and Stokes (2001) determined a ration formulation for dairy cows using an MOP that combines three objective functions that minimizes cost, nitrogen, and phosphorus excretion. Compromise solution obtained from the MINIMAX formulation show that for a little increase in the cost, nitrogen and phosphorus excretion can be reduced significantly. This solution makes it possible for dairy farmers to manage the nitrogen and phosphorus problems to improve rations.

Similarly, Jean dit Bailleul et al. (2001) reduced both cost and nitrogen excretion in pig diets with a multi-objective optimization method by modifying the traditional least-cost formulation algorithm. Weighted excesses of dietary amino acid were taken into the objective function. The method evaluation is based on the economic and environmental consequences. Pomar et al. (2007) conducted a similar study as Jean dit Bailleul et al. (2001). A multi-objective optimization model was developed based on the traditional least-cost formulation program to minimize feed cost and total phosphorus content in pig feeds. Zhang and Roush (2002) applied multiple-objective goal programming to formulate broiler grower rations that minimize nutrient variance and ration cost. The model includes soft constraints (meeting nutrient requirements, ingredient restrictions, and nutrient ratios), and hard constraints (least-cost ration and minimal nutrient variances). Solution with the least cost and solutions with minimal nutrient variability are solution from conflicting objectives that cannot be reached using a linear program. However, finding a tradeoff or acceptable ration formulation among them using the proposed method can lead to an effective compromise solution.

Castrodeza et al. (2005) constructed a multi-criteria fractional model considering nutritional, economic and environmental factors, with advanced nutritional concepts in ratio form. Besides determining the lowest possible cost, the approach considered some aspects such as maximizing diet efficiency and minimizing nutrient excess that is harmful to the environment. The interactive multiple goal programming (IMGP) method is implemented to solve the problem and the model's application is demonstrated to determine growing pig feed formulation. Babić and Perić (2011) pointed that optimization of feed ingredients blend is a multi-criteria problem. In addition to determining a feed blend for pigs that satisfies nutrient requirements at an optimal cost, the authors considered meal quality where different requirements of decision makers are modeled by using goal programming (GP). The model includes blend preparation costs, blend demand of animals, and blend quality. A multi-criteria linear programming (MCLP) model was constructed with three criteria: cost, nutrients needed to maximize weight gain in animals, and nutrients needed to maximize blend quality in terms of shelf life. The authors then reformulated the model into a GP model, where decision makers can choose optimal solutions interactively by changing the priorities of the goals through the formulated model.

In real problems, another aspect that decision makers face is uncertainty. Input data or related parameters such as feed demand, market price of RMs, RM supply availability and their nutrient provisions, frequently are generally uncertain or imprecise. To incorporate uncertainty to the problem, Rahman and Bender (1971) derived a linear approximation of the variance equation that can be incorporated to the LP formulation of the least-cost feed mix problem to take into account the variance in the model parameters, i.e. nutrient components. Two methods of linearization of the variance expression, Taylor series and a direct approximation, are presented. Peña et al. (2009) formulated a multiple objective stochastic model that allows the cost of the ration to be balanced with the probability of fulfilling the animal's nutrient requirements. The single objective minimum cost model considered the nutrient variability with stochastic constraints that specify the probability of achieving the desired nutrient contents in a ration in advance. Composition of animal diets is evaluated by the cost of the feed and the probability of achieving the desired nutrient contents in a ration. The model was applied to determine the most suitable diet for growing pigs in a real-life problem and solved by using the IMGP method. The developed stochastic model can give feed manufacturers the solution that can be adjusted to meet animal requirements and reduce environmental damage. Saxena and Khanna (2017) used models of linear, stochastic and weighted goal programming to develop some algorithms that incorporate variability of different nutrients to minimize the deviations of the minimal cost and of the maximum shelf life for dairy cow feed mix. Constraints on nutritional requirements at different stages of livestock are formulated and satisfied depending on the priorities and weights of different objectives, which lead to more practical results. The method can give more balanced feed mix solution, which can optimize multiple objectives simultaneously.

Considering the problems using fuzzy methods is another approach to tackle the lack of accuracy or precision of the data. Zadeh (1978) was the first to present the theory of possibility, which is related to the theory of fuzzy sets. The essence of the theory of possibility stems from the perspective that much information on which human decisions are based on is possibilistic rather than probabilistic in nature. Cadenas et al. (2004) applied fuzzy optimization to diet problems in Argentina farm. The objective function is to minimize cost, while satisfying the nutritional needs. Considering fuzzy constraints in which the decision makers allow small violations of the constraints, the problem is modelled as a FLP and solved by using a decision support system (DSS). With an illustrated example of cattle diet problems, the decision makers can determine a set of diets with satisfactory cost intervals. Peric and Babic (2010) developed a fuzzy multi-criteria programming model to optimize feed blend production for different kinds and categories of livestock under vague conditions. The method is applied to solve a problem of a pig farming company. Criteria for optimization of feed blend production are cost, share of ingredients necessary to maximize weight gain, and share of ingredients that negatively affect the blend quality. Constraints include minimum and maximum nutrient requirements of animal, market conditions in terms of ingredient availability and feed demand. The proposed method required decision makers to determine the weights of criteria functions and constraints. The method also allowed a weak non-dominated solution with criteria that reflects the preferences of the decision makers. Sensitivity of the obtained results in terms of changes in criteria function weights was tested to help the decision maker in selection of the preferred solution.

In addition to various mathematical models, heuristics approaches are used in the following studies. Şahman et al. (2009) proposed an approach to determining least-cost feed mixes that satisfy nutrient requirements for some livestock using Genetic Algorithm (GA). The cost optimization of feeds considered growing styles, age, nutrient requirements of poultry and different types of animals. The proposed method was compared with the LP approach to evaluate its performance. The experiments implemented by a developed software framework using Delphi environment indicated that GA method is an efficient tool to feed mix optimization. Chagwiza et al. (2016) formulated a mixed integer programming (MIP) model for the feed ration formulation of broiler with the objective function is to maximize the profit, and then presented the Bat Algorithm for solving the problem. Besides nutrient requirement constraints, the weight limit constraint is taken as an important constraint to include aspect of palatability of the feed ration in the model. Solutions from the Bat algorithm dominated that of Cplex Solver (an optimization tool) in terms of execution time and number of iterations. It can be concluded that the Bat algorithm can give better solutions with less computational time as it can identify useless solution paths without visiting them.

2.2 Research gap

Our paper aims at filling a number of important gaps in the scope of the problem under study. To the best of our knowledge, our paper is the first that focuses on RM sourcing decisions, and includes multiple feeds for major livestock sharing the same RMs supplies at the industry level. In addition, for each livestock, we appropriately consider different feed types according to its stages of growth and estimate the respective feed demands accordingly. Another unique characteristic of our paper is that the problem is solved from the perspective of the policy maker. Impacts of the government policies on the imported RM that is currently in effect and also is recently revised are measured using our proposed model. The results lead to policy evaluation and recommendations based on tradeoffs between benefit gained by the domestic farmers and loss in competitiveness of the feed industry. Furthermore, the problem is formulated as an FLP model to study the impact of uncertainty on the results.

CHAPTER 3
PROBLEM DESCRIPTION

This paper considers a RM requirement planning problem for the feed industry under different government policies in Thailand. This section describes the detail of the problem characteristics.

3.1 Types of feed and nutrient requirement

Feeds for three major livestock (broiler, hen, and swine) are categorized into eight types of feed according to their stages of growth. This is because livestock at different stages have different nutrient requirements. Broilers have three stages: starters with age of less than three weeks, growers from three to six weeks old, and finishers from six or more weeks old. Swine also have three stages: starters with weight from 15 to 25 kg, growers from 25 to 50 kg, and finishers from 50 kg or more. Hens have two stages, consisting of pullets, the early stage before they can lay eggs, and layers, the mature stage when they are ready to lay eggs. For the nutrient requirements, this paper only considers the two major nutrients, which are protein and energy. This is because the scope of the problem is for RM requirement planning for the whole feed industry, unlike other feed mix problems that focus on a single manufacturer in which case several micro-nutrients are considered.

3.2 RM and period of planning horizon

Six domestic and three imported RM supplies that compete as sources of the two nutrients are listed in Table 3.1. Among domestic RMs, maize is mainly used for the feed industry, while cassava chips and rice by-products (broken rice and rice bran) are used by many other industries. Therefore, maize is the main domestic RM of interest to the government that competes with cheaper imported RM, specifically, wheat grain. As a result, the periods of planning horizon for the problem follow the 12-month cycle of maize season, from June to May of the following year. Also, the remaining amount of maize at the end of the planning horizon is an important measure of the impact of the government policies. In addition, rice bran oil and fish meal are included in the study as buffer sources and generic RMs for energy and protein, respectively, to make the problem feasible. These two RMs are particularly abundant in their respective nutrient, but they are more expensive nutrient sources. Manufacturers usually add some small percentages of these RMs so that there are sufficient nutrients in the feeds.

Table 3.1 Sources of RMs and the types of nutrient.

RM source	Protein (%)	Energy (kcal/kg)
Domestic	fish meal*	maize, cassava chips, broken rice, rice bran, rice bran oil*, fish meal
Import	dehulled soybean meal, DDGS	wheat grain, DDGS**

Note: * Fish meal and rice brand oil are generic sources of protein and energy, respectively; ** Distiller's dried grains with soluble.

3.3 Government policies and storage capacity

Government policies are incorporated to the model as constraints so as to estimate the policy impacts. These include: (1) A policy that forces the model to purchase all the available supply amounts of domestic maize, a so-called purchase all maize policy in this paper. (2) A policy that limits the total purchase amount of imported wheat grain to be no more than one-third of the total purchase amount of domestic maize, a so-called 3:1 (maize to wheat) ratio policy. (3) Similar to 3:1 ratio policy, but with addition requirement from the government that enforces feed manufacturers, who import wheat, to purchase domestic maize at a price no less than 8 THB per kg. This policy is a 3:1 ratio with restricted maize price, a 3:1 RMP policy. (4) Due to the competitive disadvantage from the 3:1 RMP ratio to the industries, the government has later revised the policy to allow only 2:1 ratio during June to August 2018. In other words, 2:1 RMP is enforced between June and August, and then 3:1 RMP from September to May of the following year. This policy is called 2:1 & 3:1 RMP. (5) Finally, the last policy is similar to the third policy with 2:1 ratio instead.

Justification for evaluating these policies are as follows. Even though the government cannot force the manufacturers to buy all available maize, the first policy is studied in order to estimate the competitive disadvantage of using more expensive domestic maize in producing feeds. The impact is measured in terms of increase in RM cost that may incur to the feed industry. For the 3:1 RMP policy, the government has enforced this policy on the feed manufacturers since January 2017, and so the government would like to investigate its impact. The 3:1 policy (without restricted maize price) is also investigated to separately estimate the impacts of 3:1 ratio and maize price restriction. The fourth policy is investigated to assess the revised policy. Although the last policy has not been approved by the policy maker, it is interesting to estimate the improvement it can make over the original 3:1 RMP and the revised policies.

Since the model aims at finding optimal purchase and usage amounts of RMs in each period to produce feeds, while the cost of RMs change from period to period due to supply availability and other factors, one must consider storage capacity to make the problem realistic. Otherwise, the model will choose to purchase a very large amount of some RMs in the periods when the cost is low to be used in several subsequent periods without considering the limitation of storage space required to keep them. Hence, the storage capacity is expressed as an amount equivalent to the number of periods (i.e. months) of the total demand. For example, a three-month storage capacity means that the storage capacity is equal to three months of the total demand (i.e. 25% of the total annual demand of all feeds combined). In addition, a RM inventory holding cost is estimated to be 10% of the weighted average cost of the RM, where the weight is the supply availability amount of each month.

CHAPTER 4

INPUT DATA AND MODEL FORMULATION

This section provides mathematical model formulations and input data. A fuzzy linear programming (FLP) model that includes uncertainty in the input data is presented to evaluate the policy impacts. The data include monthly RM costs, nutrients provided to each feed by each RM, feed nutrient requirements, domestic RMs monthly supply availability, RM requirements (expressed in minimum and maximum percentage) of each feed formulation, and monthly feed demand. Among the input data, RM cost, feed demand, RM supply availability and RM nutrient provision naturally contain fuzziness, whereas, the feed nutrient requirements are strictly specified by the livestock industry.

4.1 Input data

The input data is collected from the Department of International Trades, Ministry of Commerce to recognize prospective feed mix problem in Thailand. Table 4.1 shows all sets of data and these input data are explained as follows.

Table 4.1 Input data set of feed mix problem.

RM	Source	Feed		Nutrition	Month
Maize	Domestic	Hen	Pullet	Protein	Jun
Dehulled soybean meal	Import		Layer	Energy	Jul
Cassava chips		Broiler	Starter		Aug
Broken rice			Grower		Sep
Rice bran			Finisher		Oct
Fish meal		Swine	Starter		Nov
Rice bran oil			Grower		Dec
Wheat grain			Finisher		Jan
DDGS					Feb
					Mar
					Apr
					May

4.1.1 RM cost

In the feed industry, each RM is preprocessed into a dried state to extend its useful life so that it can be kept in a warehouse. That is, a RM cost consists of purchase cost and preprocessing cost. While preprocessing costs are fixed, RM prices fluctuate over the period of planning horizon due to many factors, e.g. supply availability, market condition, timing in the harvest season. Figure 4.1 shows the monthly price of the seven major RMs, while the price of buffer RMs (fish meal and rice bran oil) are omitted. The important issue faced by the government in this industry is from the RM prices for sources of energy. From Figure 4.1, the prices of domestic RMs (maize, broken rice, and rice bran) are higher than that of export wheat grain. This indicates the needs for the government to intervene the domestic RM market mechanism, specifically, to help the maize farmers because maize is mainly used in the feed industry. It should be noted that rice by-products can be used in other industries. In addition, although cassava chips price is the lowest, its usage in the feed industry is limited by its physical characteristic.

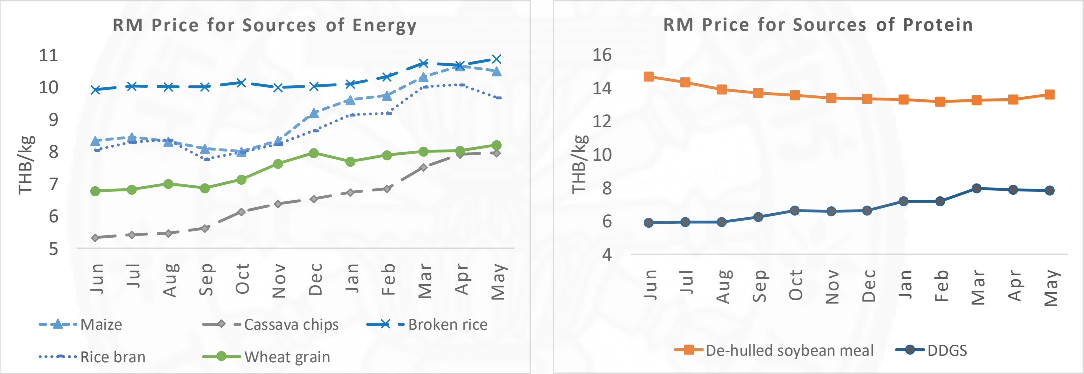


Figure 4.1 Cost of major RMs over the period of planning horizon (2017-2018)

4.1.2 Feed nutrient requirement and RM nutrient supply

On the demand side, the three livestock require different levels of nutrient depending on their growth stage. The nutrient requirement for each feed is shown in Figure 4.2.

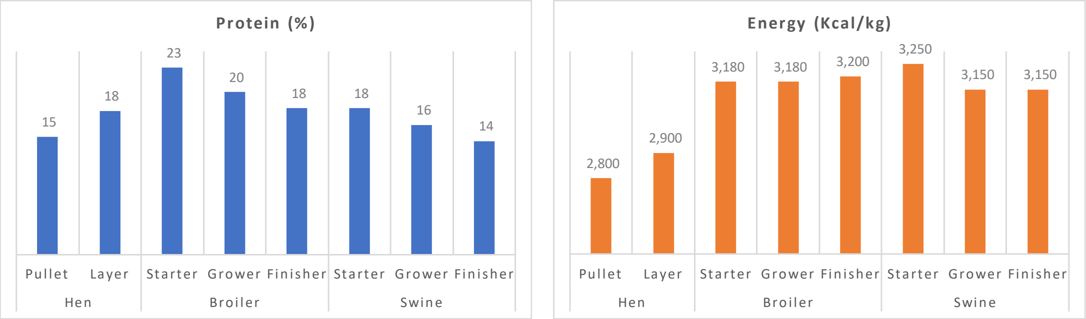


Figure 4.2 Nutrient requirement for each feed

Regarding nutrient supply, each RM may provide different percentage of protein and amount of energy when it is mixed in different feeds, as shown in Table 4.2.

Table 4.2 Nutrient provided by RM to each feed.

RM	Feed	Protein (%)	Energy (Kcal/kg)
Maize	Broiler, hen	8	3,370
	Swine	8	3,168
Cassava chips	Broiler, hen	2.5	3,500
	Swine	2.5	3,260
Broken rice	Broiler, hen	8	3,500
	Swine	8	3,596
Rice bran	Broiler, hen	12	2,710
	Swine	12	3,120
Dehulled soybean meal	Broiler, hen	44	2,280
	Swine	44	2,825
Wheat grain	Broiler, hen, swine	8	3,107
DDGS	Broiler, hen, swine	26.84	3,120
Rice bran oil	Broiler, hen, swine	0	8,400
Fish meal	Broiler, hen	60	2,950
	Swine	60	2,550

4.1.3 Domestic RMs supply availability

Available amounts of RM supplies vary according to their harvest seasons. Figure 4.3 illustrates supply availability for domestic RMs including maize, cassava chips, broken rice, and rice bran. Imported RMs (dehulled soybean meal, wheat grain, and DDGS) and buffer RMs (fish meal, rice bran oil) are assumed to have unlimited supply amounts.

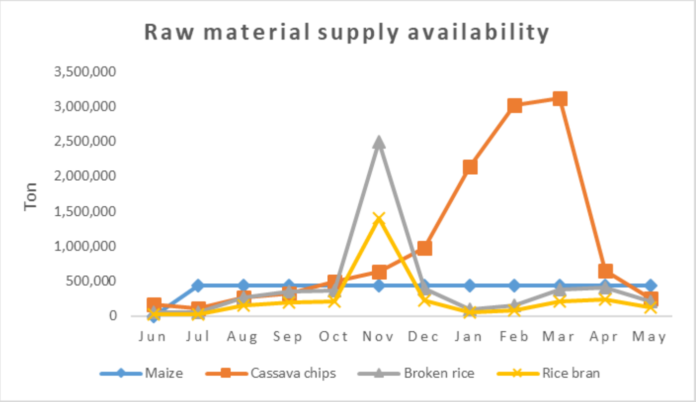


Figure 4.3 Monthly supply for each RM (2017-2018)

4.1.4 RM requirement percentage

The data regarding the minimum and maximum percentages of each RM required for each feed are from Thai Feed Mill Association (2017). These are common requirements by the feed manufacturers so that the feeds have certain physical or sensory characteristics. The data are as shown in Table 4.3.

Table 4.3 Minimum and maximum percentage of RM for each feed.

RM	Broiler			Hen		Swine		
	Starter	Grower	Finisher	Pullet	Layer	Starter	Grower	Finisher
<u>Minimum (%)</u>								
Maize	40	30	20		20			
Dehulled soybean meal							15	18
<u>Maximum (%)</u>								
Cassava chips	5	10	15	10	15		15	20
Rice bran	10	10	15	30	30	20	30	30
Wheat grain	10	20	20		20	10	20	30
DDGS	10	10	10	15	15	0	10	10
Fish meal	7	7	7	7	7	5	5	5

4.1.5 Feed demand

Feed demands are estimated on a yearly basis by the Thai Feed Mill Association (2017). Annual demand data are then projected to be monthly demand using the assumption that demand for food (broiler meat, chicken egg, and pork), and subsequently, demand for feeds are relatively constant without seasonal effects. This assumption is verified by experts in the field using monthly food consumption and feed production. Since the main domestic RM of interest is maize, the period of planning horizon follows maize harvest season (from June to May of the following year). As a result, monthly demand data are constant from June to December, and slightly shift to another level from January to May. Table 4.4 shows monthly demand for each feed.

Table 4.4 Feed demand from June to December 2017 and January to May 2018.

Harvest	Hen		Broiler			Swine		
	Pullet	Layer	Starter	Grower	Finisher	Starter	Grower	Finisher
06-12	34	185	99	292	146	84	135	151
01-05	31	189	102	301	150	87	140	157

Note: Unit (1,000 tons).

4.2 Model development

4.2.1 Fuzzy data

Generally, some of the data used in the model are subject to uncertainties. Specifically, RM costs, domestic RM supply availability, RM nutrient provision, and feed demand are imprecise over the planning horizon. A tilde symbol (~) is placed above the parameter symbols to indicate imprecise data. The imprecise data are modeled using the triangular possibility distribution. This distribution is based on historical data collected from most recent years. The maximum and minimum year-to-year percentage changes, along with a median percentage change or no change in the data are used to estimate the pessimistic, most likely and optimistic values. Among the three values, the maximum percentage is treated as optimistic, the median value as most likely, and the minimum percentage as pessimistic for feed demand and RM supply availability. The opposite is used for the RM costs. The imprecise data are projected by multiplying these percentages to the most recent year data. For example, the price of broken rice in a month (e.g. December) that was recorded in the past three years has the largest growth rate of 9%, and the smallest growth rate of -13%. Hence, the pessimistic price and optimistic price of broken rice are estimated by multiplying 1.09 and 0.87 with the most recent price, respectively. Note that the most likely value is the most recent data.

In addition, the pessimistic values of the RM provision are equal to the values shown in Table 4.2. This is because the RM used in the feed production process are required by the manufacturers to contain at least this minimum level nutrient provision. Furthermore, the feed manufacturers can only be granted a zero percent import tax exemption if the imported RMs have nutrient provision no less than the minimum level required by the government. Therefore, the manufacturers and the government agency are particularly strict on the imported RMs. The most likely and the optimistic values are assumed to be 5% and 10% larger than the pessimistic value, as suggested by the government agency. For instance, the percentage of protein that maize provides for a hen in feed can be 8% (pessimistic value), or 8.4% (most likely value), or 8.8% (optimistic value), of a weight unit. Similarly, the energy supply amount of this RM to a hen fluctuates from 3,370 kcal/kg to 3,707 kcal/kg.

4.2.2 Indices and sets

Sets notations represent RM, feed, and time period index that consists of nine types of RM supplies (domestic and imported source), two types of nutrient ingredients, and eight types of feeds demand. All notations are showed as follows.

i: RM index, $i \in M$ where $M = \{1, 2, \ldots, 9\}$ for maize, dehulled soybean meal, cassava chips, broken rice, rice bran, fish meal, rice bran oil, wheat grain, and DDGS

j: Feed index, $j \in N$ where $N = \{1, 2, \ldots, 8\}$ for hen pullet, hen layer, broiler starter, broiler grower, broiler finisher, swine starter, swine grower, and swine finisher

t: Time period index, $t \in T$ where $T = \{1, 2, \ldots, 12\}$ for June, July, …, May

4.2.2 Input parameters

Input parameters consist of six main kinds, namely, RM cost, inventory holding cost and warehouse capacity indicator, supply availability, feed demand, percentage of protein and amount of energy provided by RM, percentage of protein and amount of energy requirement for each feed, minimum and maximum percentage requirement of RM for each feed. All notations are described as below.

$\tilde{C}_{i,t}$: cost of purchase and preprocessing RM i in period t

H_i: holding cost of RM i

$\tilde{S}_{i,t}$: supply availability of RM i in period t

$\tilde{D}_{j,t}$: demand of feed j in period t

$\tilde{P}_{i,j}$: percentage of protein provided by RM i to feed j

$\tilde{E}_{i,j}$: amount of energy provided by RM i to feed j

PR_j: percentage of protein requirement for feed j

ER_j: amount of energy requirement for feed j

$L_{i,j}$: minimum percentage requirement of RM i for feed j

$U_{i,j}$: maximum percentage requirement of RM i for feed j

k: storage capacity expressed as the number of periods of RM demand

4.2.3 Decision variables

There are three sets of decision variables including purchase amount, usage amount, and ending inventory in each period as follows.

$X_{i,t}$: the amount of RM *i* purchased in period *t*

$Y_{i,j,t}$: the amount of RM *i* used to produce feed *j* in period *t*

$I_{i,t}$: ending inventory of RM *i* in period *t*

4.2.3 FLP model formulation

The problem is formulated as follows:

Minimize
$$\tilde{z} = \sum_{i\in M}\sum_{t\in T}\tilde{C}_{i,t}X_{i,t} + \sum_{i\in M}\sum_{t\in T}H_i I_{i,t} \qquad (1)$$

Subject to

$$X_{i,t} \le \tilde{S}_{i,t} \qquad \forall i \in M, \forall t \in T \qquad (2)$$

$$\sum_{i\in M} Y_{i,j,t} = \tilde{D}_{j,t} \qquad \forall j \in N, \forall t \in T \qquad (3)$$

$$\sum_{j\in N} Y_{i,j,t} + I_{i,t} = X_{i,t} + I_{i,t-1} \qquad \forall i \in M, \forall t \in T \qquad (4)$$

$$\sum_{i\in M} (\tilde{P}_{i,j}Y_{i,j,t}) \ge PR_j\tilde{D}_{j,t} \qquad \forall j \in N, \forall t \in T \qquad (5)$$

$$\sum_{i\in M} (\tilde{E}_{i,j}Y_{i,j,t}) \ge ER_j\tilde{D}_{j,t} \qquad \forall j \in N, \forall t \in T \qquad (6)$$

$$Y_{i,j,t} \ge L_{i,j}\tilde{D}_{j,t} \qquad \forall i \in M, \forall j \in N, \forall t \in T \qquad (7)$$

$$Y_{i,j,t} \le U_{i,j}\tilde{D}_{j,t} \qquad \forall i \in M, \forall j \in N, \forall t \in T \qquad (8)$$

$$X_{i,t}, Y_{i,j,t}, I_{i,t} \ge 0 \qquad \forall i \in M, \forall j \in N, \forall t \in T \qquad (9)$$

$$\sum_{i\in M} X_{i,t} + \sum_{i\in M} I_{i,t-1} \le k\,\frac{\sum_{j\in N}\sum_{t\in T}\tilde{D}_{j,t}}{12} \qquad \forall t \in T \qquad (10)$$

$$X_{1,t} = \tilde{S}_{1,t} \qquad \forall t \in T \qquad (11)$$

$$X_{1,t} \ge 3X_{8,t} \qquad \forall t \in T \qquad (12)$$

$$X_{1,t} \ge 2X_{8,t} \qquad \forall t \le 3 \qquad (13)$$

$$X_{1,t} \ge 3X_{8,t} \qquad \forall t \ge 4 \qquad (14)$$

In the model, the objective function in equation (1) is to minimize the total cost of purchase, preprocessing, and inventory holding of all RMs. Constraints (2) force that the purchase amount of each RM must not exceed the available supply amount in each period. Constraints (3) imply that the amount of all RMs used to produce each feed must satisfy feed demand in each period. Constraints (4) are the flow balance between purchase amount, usage amount, and inventory of each RM in each period. Constraints (5) and (6) specify that the percentage of protein and amount of energy supplied by all RMs that are used to produce each feed must satisfy protein and energy requirements of each feed in each period, respectively. Constraints (7) and (8) enforce the minimum and maximum percentage of each RM used to produce each feed in each period. Constraint (9) shows all variables must be positive value. In addition, the scenario analysis of warehouse capacity and government policies requires the following constraints: Constraints (10) limit the total purchase amount and ending inventory amount of all RM not to exceed the warehouse capacity in each period, Constraints (11) force all available domestic maize to be purchased, Constraints (12) specify the 3:1 ratio of maize to wheat grain purchase amounts, and both Constraints (13) and (14) combined for the 2:1 & 3:1 ratios scenario. Note that each set of constraints is included in the model only when it is required for the respective scenario analysis.

4.2.4 Modeling the imprecise data with fuzzy approach

With imprecise RM costs, RM supply availability, RM nutrient provision and feed demand, the parameters are $\tilde{C}_{i,t}$, $\tilde{S}_{i,t}$, $\widetilde{D}_{j,t}$, $\tilde{P}_{i,j}$, and $\tilde{E}_{i,j}$ where $\tilde{C}_{i,t}$ is the imprecise RM cost, $\tilde{S}_{i,t}$ is the imprecise available RM supply, $\widetilde{D}_{j,t}$ is the monthly demand, and $\tilde{P}_{i,j}, \tilde{E}_{i,j}$ are imprecise nutrients provided by RMs. These imprecise data are assumed to be in triangular possibility distribution. The possibility distribution can be stated as the degree of occurrence of an event with imprecise data. For example, the triangular possibility distribution of $\tilde{C}_{i,t}$ can be constructed based on the three prominent data, e.g. (1) The most pessimistic value ($C_{i,t}^{p}$) that has a very low likelihood of belonging to the set of available values (possibility degree = 0 if normalized). (2) The most possible value ($C_{i,t}^{m}$) that definitely belongs to the set of available value (possibility = 1 if normalized). (3) The most optimistic value ($C_{i,t}^{o}$) that has a very low likelihood of belonging to the set of available values (possibility degree = 0 if normalized).

Thus, the imprecise data can be modeled with triangular possibility distributions:

$$\tilde{C}_{i,t} = (C^p_{i,t}, C^m_{i,t}, C^o_{i,t}) \quad \forall i \in M, \forall t \in T$$
$$\tilde{S}_{i,t} = (S^p_{i,t}, S^m_{i,t}, S^o_{i,t}) \quad \forall i \in M, \forall t \in T$$
$$\tilde{D}_{j,t} = (D^p_{j,t}, D^m_{j,t}, D^o_{j,t}) \quad \forall j \in N, \forall t \in T$$
$$\tilde{P}_{i,j} = (P^p_{i,j}, P^m_{i,j}, P^o_{i,j}) \quad \forall i \in M, \forall j \in N$$
$$\tilde{E}_{i,j} = (E^p_{i,j}, E^m_{i,j}, E^o_{i,j}) \quad \forall i \in M, \forall j \in N$$

4.2.5 Multi-objective FLP problem

Applying the triangular fuzzy data, we consider the following multi-objective linear programming (MOLP), which is strongly related to the FLP problems.

Minimize

$$\tilde{z} = \sum_{i \in M} \sum_{t \in T} (C^p_{i,t}, C^m_{i,t}, C^o_{i,t}) X_{i,t} + \sum_{i \in M} \sum_{t \in T} H_i I_{i,t} \tag{15}$$

We get $\tilde{z}$ as (z^p, z^m, z^o) where,

$$z^p = \sum_{i \in M} \sum_{t \in T} C^p_{i,t} X_{i,t} + \sum_{i \in M} \sum_{t \in T} H_i I_{i,t}$$
$$z^m = \sum_{i \in M} \sum_{t \in T} C^m_{i,t} X_{i,t} + \sum_{i \in M} \sum_{t \in T} H_i I_{i,t}$$
$$z^o = \sum_{i \in M} \sum_{t \in T} C^o_{i,t} X_{i,t} + \sum_{i \in M} \sum_{t \in T} H_i I_{i,t}$$

Thus, the objective function of (15) becomes minimizing (z^p, z^m, z^o). To solve this multi-objective problem, we use Pareto's method to form weighted objective function.

Minimize $w^1 z^p + w^2 z^m + w^3 z^o$

For some $w > 0$, the optimal Pareto solution is a non-dominated solution to the fuzzy LP problem. In this problem, we assume $w^1 = w^2 = w^3 = 1$.

4.2.6 Imprecise available resources and technological coefficients

Recalling constraints (2), (3), (7), (8), (10), and (11) with fuzzy data, $\tilde{S}_{i,t}, \widetilde{D}_{j,t}$, on the right hand side of the constraints only, these are imprecise available resources and have triangular possibility distributions with the most possible value and the least possible values. Our model adopts the weighted average method to solve a possibilistic linear programming problem with imprecise objective function and/or constraint coefficients proposed by Lai and Hwang (1992) to represent the fuzzy supply and demand data. That is, $\tilde{S}_{i,t}$ becomes $w_1 S^p_{i,t} + w_2 S^m_{i,t} + w_3 S^o_{i,t}$, and $\widetilde{D}_{j,t}$ becomes $w_1 D^p_{j,t} +$

$w_2 D^m_{j,t} + w_3 D^o_{j,t}$, where $w_1 + w_2 + w_3 = 1$. It is assumed that $w_2 = \frac{4}{6}$, and $w_1 = w_3 = \frac{1}{6}$, because the most possible values usually are the most important ones, and thus should be assigned more weights.

Moreover, to solve Eq. (5) and (6) with fuzzy data, imprecise coefficients $(\tilde{P}_{i,j}, \tilde{E}_{i,j})$ and imprecise demand $(\tilde{D}_{j,t})$, on both sides of the constraints, the approach proposed here converted these inequality constraints by using fuzzy ranking concept, as follows.

$$\sum_{i \in M} (P^p_{i,j} Y_{i,j,t}) \geq PR_j D^p_{j,t} \qquad \forall j \in N, \forall t \in T$$

$$\sum_{i \in M} (P^m_{i,j} Y_{i,j,t}) \geq PR_j D^m_{j,t} \qquad \forall j \in N, \forall t \in T$$

$$\sum_{i \in M} (P^o_{i,j} Y_{i,j,t}) \geq PR_j D^o_{j,t} \qquad \forall j \in N, \forall t \in T$$

$$\sum_{i \in M} (E^p_{i,j} Y_{i,j,t}) \geq ER_j D^p_{j,t} \qquad \forall j \in N, \forall t \in T$$

$$\sum_{i \in M} (E^m_{i,j} Y_{i,j,t}) \geq ER_j D^m_{j,t} \qquad \forall j \in N, \forall t \in T$$

$$\sum_{i \in M} (E^o_{i,j} Y_{i,j,t}) \geq ER_j D^o_{j,t} \qquad \forall j \in N, \forall t \in T$$

4.2.7 The complete FLP model

Now, we can rewrite the problem as a linear programming.

Minimize

$$z = \Big(\sum_{i \in M}\sum_{t \in T} C^p_{i,t} X_{i,t} + \sum_{i \in M}\sum_{t \in T} H_i I_{i,t}\Big) + \Big(\sum_{i \in M}\sum_{t \in T} C^m_{i,t} X_{i,t} + \sum_{i \in M}\sum_{t \in T} H_i I_{i,t}\Big) + \Big(\sum_{i \in M}\sum_{t \in T} C^o_{i,t} X_{i,t} + \sum_{i \in M}\sum_{t \in T} H_i I_{i,t}\Big) \tag{16}$$

Subject to

$$X_{i,t} \leq w_1 S^p_{i,t} + w_2 S^m_{i,t} + w_3 S^o_{i,t} \qquad \forall i \in M, \forall t \in T \tag{17}$$

$$\sum_{i \in M} Y_{i,j,t} = w_1 D^p_{j,t} + w_2 D^m_{j,t} + w_3 D^o_{j,t} \qquad \forall j \in N, \forall t \in T \tag{18}$$

$$\sum_{j \in N} Y_{i,j,t} + I_{i,t} = X_{i,t} + I_{i,t-1} \qquad \forall i \in M, \forall t \in T \tag{19}$$

$$\sum_{i \in M} (P^p_{i,j} Y_{i,j,t}) \geq PR_j D^p_{j,t} \qquad \forall j \in N, \forall t \in T \tag{20}$$

$$\sum_{i \in M} (P^m_{i,j} Y_{i,j,t}) \geq PR_j D^m_{j,t} \qquad \forall j \in N, \forall t \in T \tag{21}$$

$$\sum_{i \in M} (P_{i,j}^{o} Y_{i,j,t}) \geq PR_j D_{j,t}^{o} \qquad \forall j \in N, \forall t \in T \qquad (22)$$

$$\sum_{i \in M} (E_{i,j}^{p} Y_{i,j,t}) \geq ER_j D_{j,t}^{p} \qquad \forall j \in N, \forall t \in T \qquad (23)$$

$$\sum_{i \in M} (E_{i,j}^{m} Y_{i,j,t}) \geq ER_j D_{j,t}^{m} \qquad \forall j \in N, \forall t \in T \qquad (24)$$

$$\sum_{i \in M} (E_{i,j}^{o} Y_{i,j,t}) \geq ER_j D_{j,t}^{o} \qquad \forall j \in N, \forall t \in T \qquad (25)$$

$$Y_{i,j,t} \geq L_{i,j} \left(w_1 D_{j,t}^{p} + w_2 D_{j,t}^{m} + w_3 D_{j,t}^{o} \right) \qquad \forall i \in M, \forall j \in N, \forall t \in T \qquad (26)$$

$$Y_{i,j,t} \leq U_{i,j} \left(w_1 D_{j,t}^{p} + w_2 D_{j,t}^{m} + w_3 D_{j,t}^{o} \right) \qquad \forall i \in M, \forall j \in N, \forall t \in T \qquad (27)$$

$$X_{i,t}, Y_{i,j,t}, I_{i,t} \geq 0 \qquad \forall i \in M, \forall j \in N, \forall t \in T \qquad (28)$$

The policy analysis of storage capacity and government policies' constraints now become as follows.

$$\sum_{i \in M} X_{i,t} + \sum_{i \in M} I_{i,t-1} \leq k \frac{\sum_{j \in N} \sum_{t \in T} (w_1 D_{j,t}^{p} + w_2 D_{j,t}^{m} + w_3 D_{j,t}^{o})}{12} \qquad \forall t \in T \qquad (29)$$

$$X_{1,t} = w_1 S_{1,t}^{p} + w_2 S_{1,t}^{m} + w_3 S_{1,t}^{o} \qquad \forall t \in T \qquad (30)$$

$$X_{1,t} \geq 3X_{8,t} \qquad \forall t \in T \qquad (31)$$

$$X_{1,t} \geq 2X_{8,t} \qquad \forall t \leq 3 \qquad (32)$$

$$X_{1,t} \geq 3X_{8,t} \qquad \forall t \geq 4 \qquad (33)$$

CHAPTER 5
RESULTS AND DISCUSSIONS

This chapter includes two part: (1) base case results, consisting of total cost, purchase amount, usage amount, inventory amount, purchase cost of each RM, average cost of each feed, and remaining amount of domestics RM at the end of planning horizon; (2) scenarios analysis estimated the influence of government policies and warehouse capacity on key measures of performance are shown as follows.

5.1 Base case results

The results show that the imprecise total cost has a triangular possibility of (106,892; 123,975; 134,043) million THB. Monthly purchase, usage, and ending inventory amounts of RMs are shown in Tables 5.1, 5.2, and 5.3, respectively. The total purchase amount of maize is 3.01 million tons from the imprecise available supply of 4.88 million tons (i.e. 62% usage). Under uncertainty, de-hulled soybean meal is purchased during the 1st half of the season. There is a large amount of purchase in December to be used in the 2nd half of the season. Similarly, wheat grains are purchased only once at the beginning of the season. This is because the imprecise price of wheat grains in June is at the lowest and increases after that month. Table 5.4 shows the monthly remaining amount and value of maize.

Table 5.1 Monthly purchase amount of each RM (1,000 tons).

RM	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb - May
Maize		444	444	444	444	444	444	352	
Cassava chips	157	103	261	312	482	363			
Broken rice	46	10	10	41		23	142		
Rice bran	26	26	157	205	211	648			
De-hulled soybean meal	549	272	263	544		276	1,698		
Wheat grain	2,791								
DDGS	120	1,304							

Table 5.2 Monthly usage amount of each RM (1,000 tons).

RM	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Maize		441	298	277	245	245	245	253	253	253	253	253
Cassava chips	141	119	136	136	141	141	141	145	145	145	145	145
Broken rice	46	10	10	17	23	23	23	24	24	24	24	24
Rice bran	26	26	149	111	118	118	118	122	122	122	122	122
De-hulled soybean meal	549	272	263	268	276	276	276	284	284	284	284	284
Wheat grain	251	181	195	241	238	238	238	242	242	242	242	242
DDGS	120	114	109	109	120	120	120	123	123	123	123	123

Table 5.3 Monthly ending inventory amount of each RM (1,000 tons).

RM	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Maize		3	148	316	514	713	912	1,011	758	505	253
Cassava chips	16		126	302	643	866	725	580	435	290	145
Broken rice				23			119	95	72	48	24
Rice bran			8	103	196	726	608	487	365	243	122
De-hulled soybean meal				276			1,421	1,137	853	569	284
Wheat grain	2,540	2,360	2,165	1,924	1,686	1,448	1,211	969	726	484	242
DDGS		1,190	1,081	971	852	732	613	490	368	245	123

Table 5.4 Monthly remaining amount (1,000 tons) and value (million THB) of maize.

Remaining maize	Jan	Feb	Mar	Apr	May	Total
Amount	92	444	444	444	444	1,869
Optimistic value	889	4,330	4,583	4,738	4,663	19,202
Most likely value	897	4,455	4,725	4,865	4,827	19,769
Pessimistic value	914	4,509	5,041	5,411	5,209	21,084

Figure 5.1 shows the average cost of feed per kg for hen, broiler and swine. In each bar chart, three values of the cost are provided for each stage of the feed. The optimistic, most likely and pessimistic average costs for every stage of broiler feed are always the highest. The average cost per kg of pullet hen is lower than that of layer hen,

whereas, for broiler and swine, the average costs of their feeds become lower as they grow older.

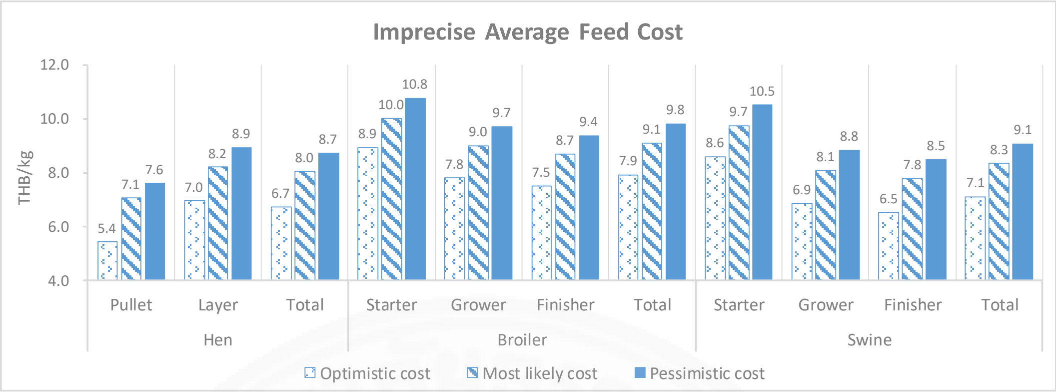


Figure 5.1 Imprecise average feed cost of hen, broiler, and swine.

5.2 Scenario analysis

The scenarios analysis is conducted to estimate the impact of government policies and storage capacity on key system measures of performance. These include the total cost and average cost of each feed, which are important to the feed manufacturers, and the total remaining amount of maize at the end of the planning horizon, which is important to the farmers.

5.2.1 Total cost and average feed cost

In relation to total cost and average feed cost, the imprecise total costs under different government policies and storage capacity are provided in three graphs of Figure 5.2. Regarding government policies, the total costs rank in an ascending order from the base case, purchase all maize, 3:1, 2:1 RMP, 2:1 & 3:1 RMP, and 3:1 RMP. For storage capacity, the most likely and pessimistic total costs increase as the storage capacity decreases. Meanwhile, the optimistic total cost reaches the lowest when storage capacity is at an equivalent of three months (k = 3) of feed demands in all policies (except for purchase all maize policy, which has the lowest cost when k = 2.5), then starts to increase as the storage capacity becomes lower. This pattern occurs because the imprecise costs are subject to one optimal solution.

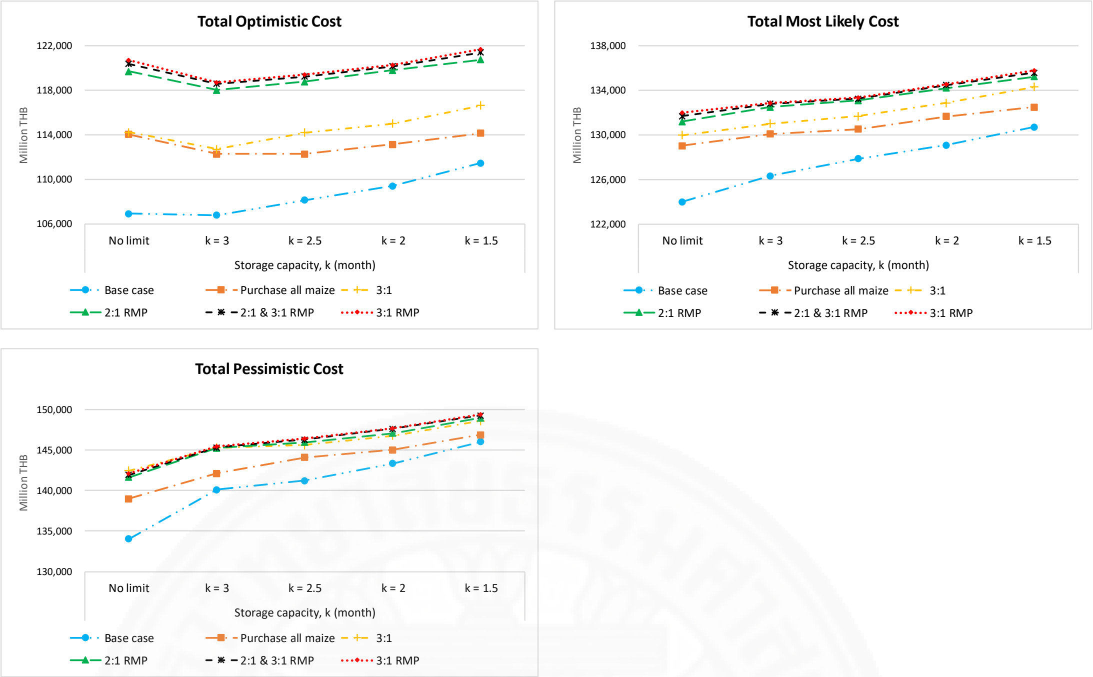


Figure 5.2 The total cost (million THB).

For each value of the imprecise total cost, the percentage increase for all government policies compared to the base case are shown in Table 5.5 to 5.7. The imprecise total costs for the "purchase all maize" policy increase by the smallest percentages (see the first rows of Table 5.5 to 5.7), whereas, the 3:1 RMP policy results in the largest percentage increase (see the last rows of Table 5.5 to 5.7). For the feed industry, this policy has the highest impact among all policies.

Table 5.5 Percentage increase in the optimistic total cost compared to the base case.

Policies	No limit	Storage capacity, k (month)			
		k = 3	k = 2.5	k = 2	k = 1.5
Purchase all maize	6.7%	5.2%	3.8%	3.4%	2.4%
3:1	6.8%	5.6%	5.6%	5.1%	4.6%
2:1 RMP	12.0%	10.5%	9.8%	9.5%	8.3%
2:1 & 3:1 RMP	12.6%	11.1%	10.3%	9.8%	8.9%
3:1 RMP	12.9%	11.2%	10.4%	9.9%	9.2%

Table 5.6 Percentage increase in the most likely total cost compared to the base case.

Policies	No limit	Storage capacity, k (month)			
		k = 3	k = 2.5	k = 2	k = 1.5
Purchase all maize	4.1%	3.0%	2.1%	2.0%	1.4%

3:1	4.8%	3.7%	3.0%	3.0%	2.8%
2:1 RMP	5.8%	4.9%	4.1%	4.0%	3.5%
2:1 & 3:1 RMP	6.2%	5.1%	4.2%	4.2%	3.7%
3:1 RMP	6.4%	5.2%	4.3%	4.2%	3.9%

Table 5.7 Percentage increase in the pessimistic total cost compared to the base case.

Policies	No limit	Storage capacity, k (month)			
		k = 3	k = 2.5	k = 2	k = 1.5
Purchase all maize	3.7%	1.4%	2.0%	1.2%	0.6%
3:1	6.3%	3.7%	3.1%	2.4%	1.8%
2:1 RMP	5.7%	3.7%	3.3%	2.6%	2.0%
2:1 & 3:1 RMP	5.9%	3.7%	3.6%	3.0%	2.2%
3:1 RMP	6.0%	3.8%	3.7%	3.0%	2.3%

It is also of interest to the government policy maker to look at the total cost of the whole feed industry. Impacts of government policies on the imprecise total cost when compared to the base case also are analyzed. When the 3:1 RMP policy is replaced by the 2:1 & 3:1 RMP policy, the percentage increase is slightly reduced in the imprecise total cost: 0.1%-0.3% reduction in the optimistic cost, 0.1%-0.2% in the most likely cost, and 0.1% in the pessimistic cost. That is, the revised policy has a little effect on the total cost. If the 3:1 RMP policy is replaced by the 2:1 RMP for the whole season, then the percentage increase in the total cost may be reduced by 0.4%-0.9% in the optimistic cost, 0.2%-0.6% in the most likely cost, and 0.2%-0.4% in the pessimistic cost, which is slightly more effective than the mixed 2:1 & 3:1 RMP. The 3:1 policy (with no restriction on domestic maize price on the manufacturer) is more effective to replace the 3:1 RMP policy than the 2:1 RMP because it can reduce the percentage increase in the imprecise total cost by 4.6%-6.1% (in the optimistic cost), 1.1%-1.6% (in the most likely cost), and 0.1%-0.6% (in the pessimistic cost, except for the no limit capacity).

Figures 5.3, 5.4, and 5.5 show the imprecise average feed costs of hen, broiler, and swine, respectively, for various policies and at different storage capacity levels.

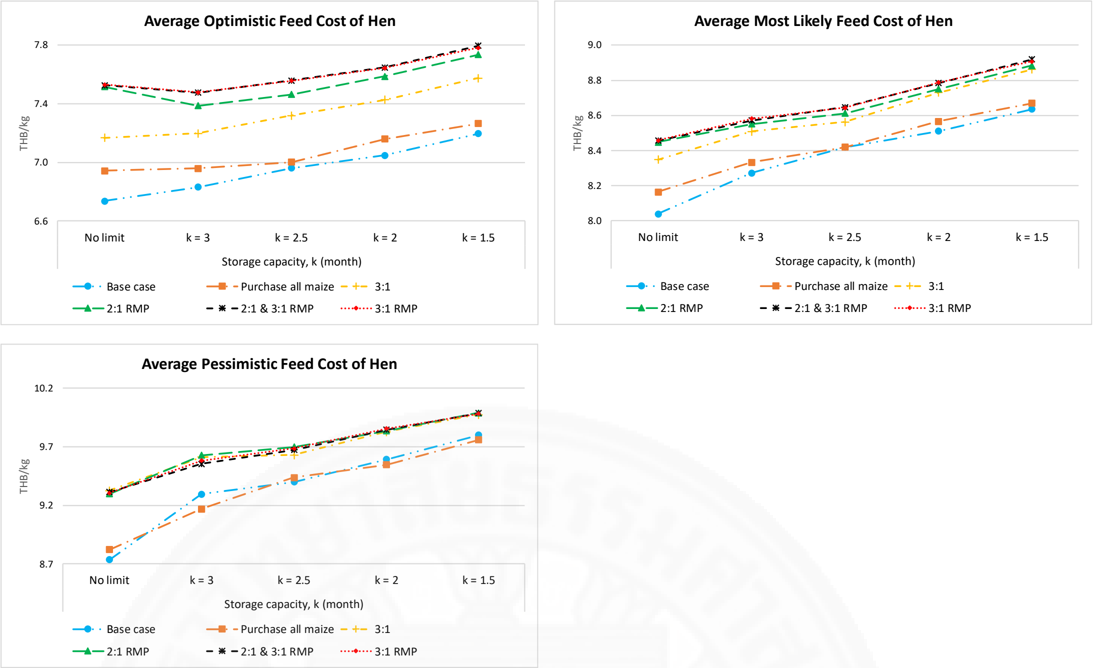


Figure 5.3 The imprecise average feed cost of hen.

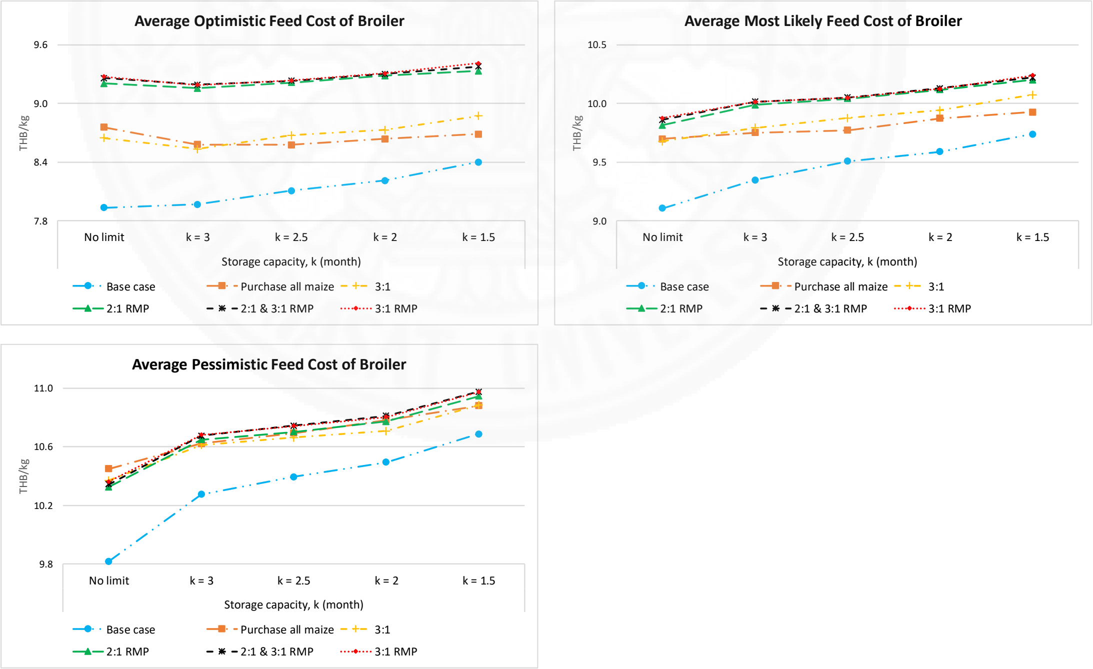


Figure 5.4 The imprecise average feed cost of broiler.

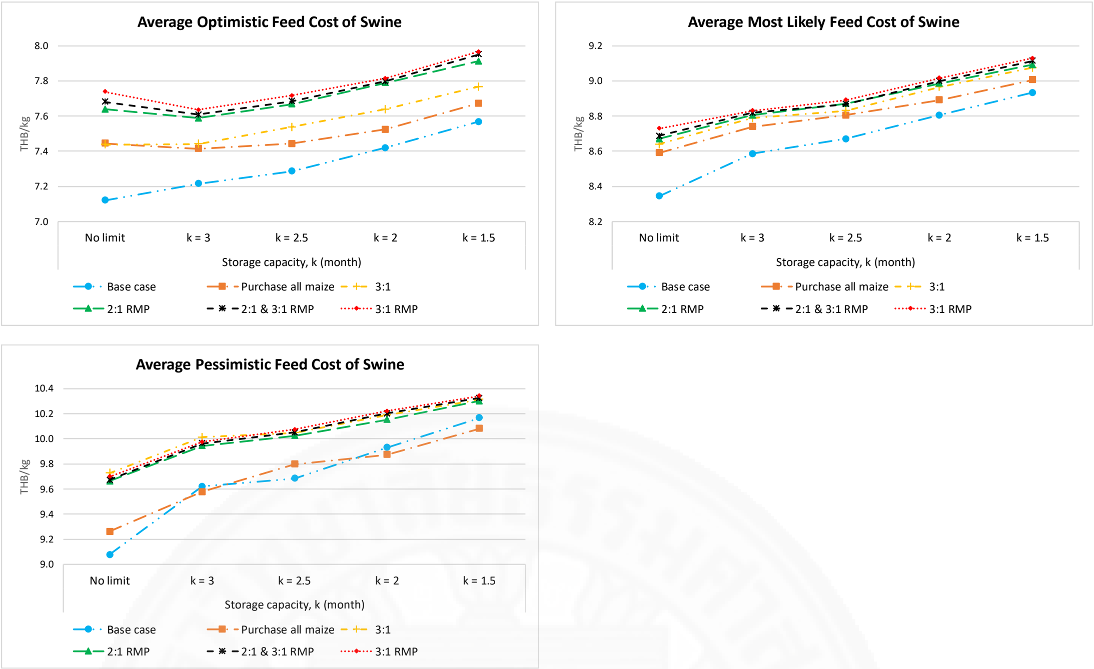


Figure 5.5 The imprecise average feed cost of swine.

First, from the figures, regarding the storage space levels, there is a common trend of the imprecise average feed cost for all three feeds. That is, the average imprecise cost tends to increase, as the storage capacity decreases. Second, regarding different government policies, the average imprecise feed costs, in most cases, can be ranked in an ascending order as follows: base case, purchase-all-maize, 3:1, 2:1 RMP, 2:1 & 3:1 RMP, and 3:1 RMP. A closer look reveals that there are groups of policies that have relatively the same average feed costs. These groups are summarized in Table 5.8.

Table 5.8 The summarized average feed cost in the model.

Imprecise cost	Feed		
	Hen	Broiler	Swine
Optimistic cost	BC < PAM < 3:1 < 2:1 RMP < 2:1 & 3:1 RMP, 3:1 RMP	BC < PAM, 3:1 < 2:1 RMP, 2:1 & 3:1 RMP, 3:1 RMP	BC < PAM < 3:1 < 2:1 RMP, 2:1 & 3:1 RMP, 3:1 RMP
Most likely cost	BC < PAM < 3:1 < 2:1 RMP < 2:1 & 3:1 RMP, 3:1 RMP	BC < PAM, 3:1 < 2:1 RMP, 2:1 & 3:1 RMP, 3:1 RMP	BC < PAM < 3:1, 2:1 RMP, 2:1 & 3:1 RMP, 3:1 RMP
Pessimistic cost	BC < PAM < 3:1, 2:1 RMP, 2:1 & 3:1 RMP, 3:1 RMP	BC < PAM, 3:1, 2:1 RMP, 2:1 & 3:1 RMP, 3:1 RMP	BC < PAM < 3:1, 2:1 RMP, 2:1 & 3:1 RMP, 3:1 RMP

Note: BC represents base case, PAM represents purchase all maize.

In the Table 5.8, policies with relatively the same average feed costs are grouped using a “comma” sign, whereas a group of policies that have lower average feed costs than another group are separated by using a “less than” (<) sign. For example, for the optimistic average feed cost of hen, there are five groups of policies: each of the four policies including base case, purchase all maize, 3:1, 2:1 RMP, is a group by itself, while 2:1 & 3:1 RMP and 3:1 RMP are in the same group. In another example, for the pessimistic average feed cost of swine, base case and purchase all maize are in the same group, while the other four policies are in a different group with higher average feed costs.

It can be seen that the effects of government policies are (1) relatively more significant for optimistic and most likely average feed costs for hen and broiler; (2) the effects of "maize to wheat ratio" policies, i.e. 3:1, 2:1 RMP, 2:1 & 3:1 RMP, and 3:1 RMP, seem to diminish for the pessimistic average feed costs of hen and broiler, as well as all three imprecise average feed costs of swine.

5.2.2 Remaining amount and value of maize

The remaining amounts and value of maize at the end of the planning horizon are as showed in Table 5.9 to 5.12, and Figure 5.6. The percentage of the remaining maize in the base case is 38%. Nevertheless, it is still very high to Thai farmers. When the 3:1 RMP is revised to the 2:1 & 3:1 RMP, the remaining amounts of maize increase by approximately 9%, while the imprecise total cost has negligible reductions. If the 2:1 RMP policy is used for the whole season instead, it will increase the total amount of remaining maize by 6.75-24.83% from the current estimates of the remaining amount of the 3:1 RMP.

The effective policy is the 3:1 policy without restriction on maize price. This policy not only reduces the imprecise total cost, but it also reduces the remaining amount of maize by up to 7.22% compared to the 3:1 RMP policy.

Table 5.9 Remaining amount (1,000 tons) of maize under various policies and storage capacity.

Policies	No limit	Storage capacity, k (month)			
		k = 3	k = 2.5	k = 2	k = 1.5

Base case	1,869	1,837	1,837	1,835	1,649
3:1	1,776	1,500	1,380	1,332	1,331
2:1 RMP	1,915	1,708	1,736	1,604	1,667
2:1 & 3:1 RMP	1,869	1,631	1,538	1,564	1,416
3:1 RMP	1,794	1,510	1,486	1,435	1,336

Table 5.10 Remaining optimistic value (million THB) of maize under various policies and storage capacity.

Policies	No limit	Storage capacity, k (month)			
		k = 3	k = 2.5	k = 2	k = 3
Base case	19,202	18,078	18,078	17,973	15,612
3:1	18,314	15,308	13,368	12,857	12,193
2:1 RMP	19,334	17,172	17,164	15,766	16,055
2:1 & 3:1 RMP	18,881	16,329	15,310	15,443	13,731
3:1 RMP	18,153	15,142	14,807	14,270	13,009

Table 5.11 Remaining most likely value (million THB) of maize under various policies and storage capacity.

Policies	No limit	Storage capacity, k (month)			
		k = 3	k = 2.5	k = 2	k = 3
Base case	19,769	19,103	19,103	18,972	16,676
3:1	18,872	15,963	14,251	13,721	13,231
2:1 RMP	19,904	17,623	17,573	16,136	16,381
2:1 & 3:1 RMP	19,438	16,732	15,659	15,767	14,013
3:1 RMP	18,689	15,521	15,146	14,594	13,284

Table 5.12 Remaining pessimistic value (million THB) of maize under various policies and storage capacity.

Policies	No limit	Storage capacity, k (month)			
		k = 3	k = 2.5	k = 2	k = 3
Base case	21,084	21,334	21,334	21,136	18,610
3:1	20,170	17,575	16,163	15,587	14,846
2:1 RMP	22,141	19,533	19,592	18,018	17,911
2:1 & 3:1 RMP	21,669	18,489	17,245	17,269	15,198
3:1 RMP	20,911	17,203	16,698	16,099	14,405

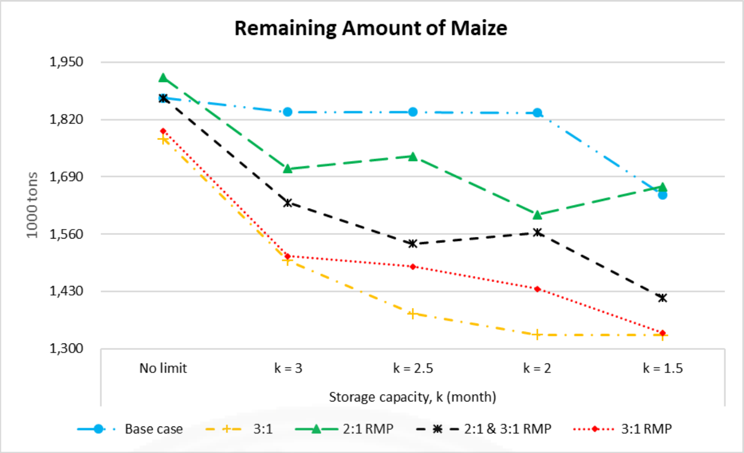


Figure 5.6 Maize remaining amount under various policies and storage capacity.

5.2.3 Percentage of RMs in each feed

Figures 5.7 show percentages of RMs in each of the three feeds for the case that the storage capacity can hold an equivalent of two months (k = 2) of feed demands. Maize is used at the highest percentage in broiler feeds, then in hen feeds, and lowest in swine feeds. The opposite trend can be observed for wheat grains usage. This suggests an appropriate matching between the source of energy from RM and energy demand from feeds that results in the lowest total cost for the feed industry.

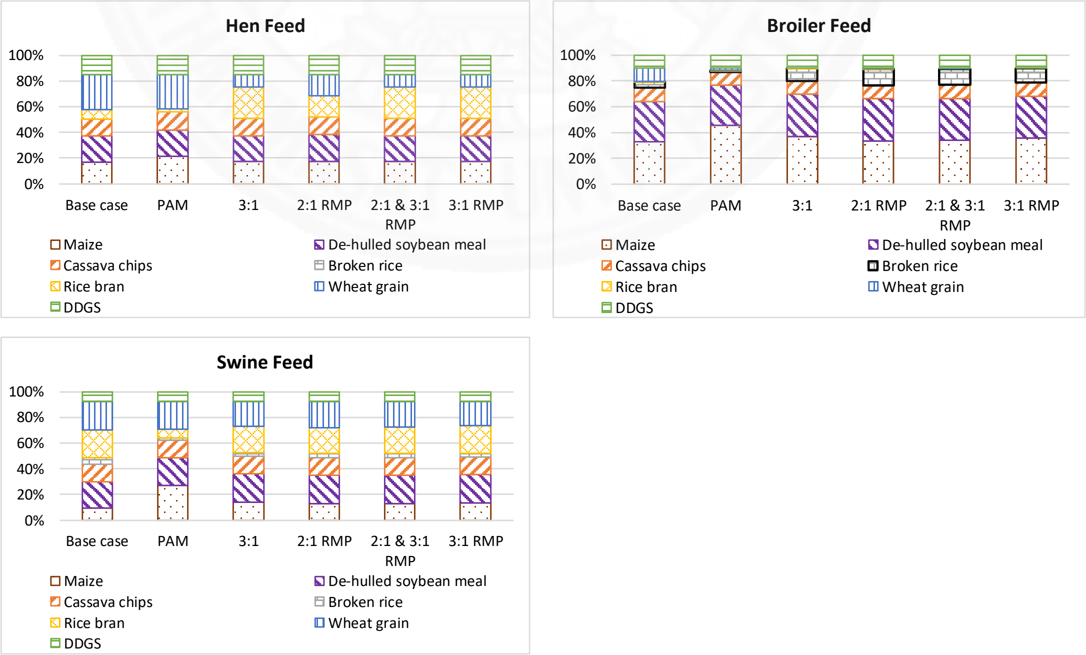
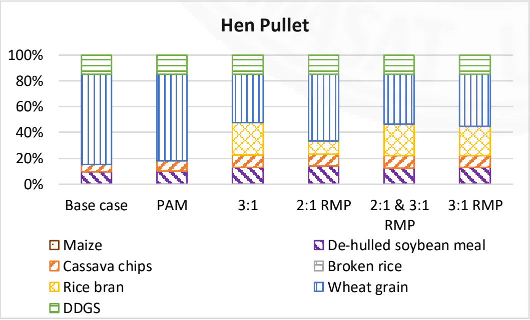
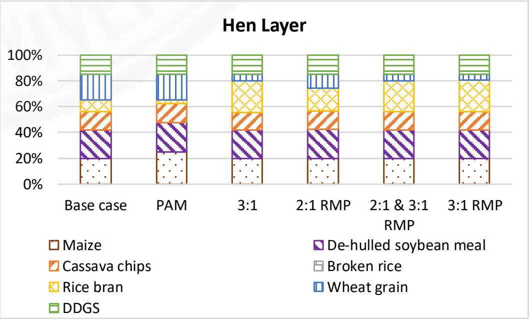


Figure 5.7 Percentages of RMs in each of the three feeds.

Figures 5.8 show the average percentages of RMs in the eight feeds. There are two types of feed formula for hen pullet: (1) the composition which includes four RMs (de-hulled soybean meal, cassava chips, wheat grain, and DDGS) in the base case and purchase all maize policy, with very high percentage of wheat grain, (2) in other four policies, there is the same formula but adding a certain percentage of rice bran. For hen layer feed, there is only one composition, including all RMs except for broken rice, at different percentages among policies. In broiler feeds, there are four RMs (maize, de-hulled soybean meal, cassava chips, and DDGS) used in broiler starters with high percentages of maize in all six policies. Then, in broiler grower feed, a certain amount of wheat grain is added in the base case, and very small percentages of broken rice are added in all policies. Feed for broiler finisher has similar compositions as ones for broiler grower in every policy. For swine starter feed, there are five RMs usage (no cassava chips and DDGS). Maize accounts for a large percentage in purchase all maize policy, but very small percentages in other policies. Feeds for swine grower and swine finisher have the same formula in each policy. That is, in purchase all maize case, the composition includes six RMs (no broken rice), and consisting of almost all RMs in other policies, but with very small percentages of maize. It is worth noting that, for broiler, the percentage of broken rice increases as the livestock grows up. By contrast, the percentage of broken rice decreases as swine grows up, and totally disappear in the feed for swine finisher.





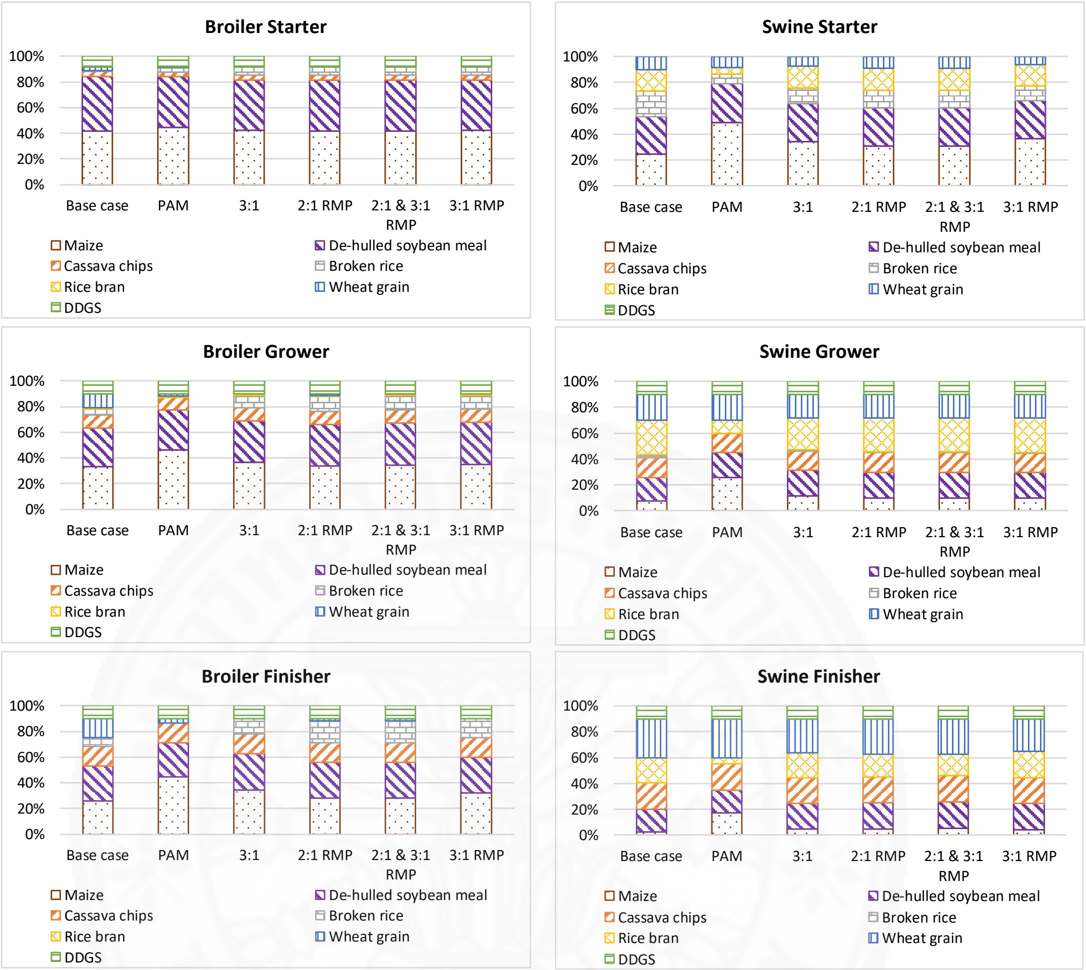


Figure 5.8 Percentages of RMs in the eight feed.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

This chapter consists of 2 sections. Section 6.1 is the conclusion and section 6.2 discusses about future research as follows.

6.1 Conclusions

In this paper, an FLP model for feed raw material sourcing problem was developed to provide a guideline for matching feed demand and RM supplies under various policies and storage capacity. The FLP model considers uncertainty in RM cost and supply availability, RM nutrient provision, and feed demand. Solving the FLP model can provide a more robust solution to the feed industry, which leads to more reliable estimates of the government policy impacts.

We consider the total cost, average feed cost, and the remaining maize as key system measures of performance. Based on the results, among the import restriction policies, the 3:1 policy without restriction on domestic maize price is the most effective both for the feed manufacturers and maize farmers. However, without restriction on maize price, the revenue of Thai farmers may reduce by 1.1%-2.1%. A policy that is more effective than the import restriction policies is the purchase all maize. This requires the feed manufacturers and farmer representatives to work together, so that the manufacturers agree to always purchase domestic maize at the factory gate at market price. This would benefit both sides in a way that the farmers' harvest would always be purchased at the fair market price, and not a restricted price by the government.

In summary, our contributions include (1) the findings suggest a robust solution regarding RM sourcing decisions for the feed industry, as well as appropriate policies under uncertain environment, and (2) the formulated FLP model can help the government policy makers to effectively evaluate future policies against the current policies.

6.2 Recommendations

Future research directions are to extend the problem to include (1) more types of raw materials, nutrients, and feeds, and (2) appropriate timing decision for the policies to be in effect, since in our study the policies are in effect for the whole season.

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APPENDIX

IBM CPLEX CODING FOR FLP MODEL

```
//Sets
{string} RM=...; //Number of RM
{string} Fd=...; //Number of feed
range T=1..12; //Number of time periods

//Weights for most likely cases: for Supply and Demand
float w=4/6;

//Weights for MOLP: Calculate Total cost (multi-objective linear programming
problem)
float w1=1;
float w2=1;
float w3=1;


//Parameters
float H[RM]=...; //Holding cost of RM i
float PR[Fd]=...; // % of protein requirement for feed j
float ER[Fd]=...; //Amount of energy requirement for feed j
float L[RM][Fd]=...; //Min % RM
float U[RM][Fd]=...; //Max % RM

float k=3; //WH Cap in k month (1.5/2/2.5/3)

//****Fuzzy parameters:
float C1[RM][T]=...; //Low cost
float C2[RM][T]=...; //Cost of purchase and preprocessing RM i in period t
float C3[RM][T]=...; //High cost

float S1[RM][T]=...; //pessimistic - low supply
float S2[RM][T]=...; //Supply availability of RM i in period t
float S3[RM][T]=...; //optimistic - high supply

float D1[Fd][T]=...; //pessimistic - low demand
float D2[Fd][T]=...; //Demand of feed j in period t
float D3[Fd][T]=...; //optimistic - high demand

float P1[RM][Fd]=...; // low
float P2[RM][Fd]=...; // % of protein provided by RM i to feed j
float P3[RM][Fd]=...; // high

float E1[RM][Fd]=...; //low
float E2[RM][Fd]=...; //Amount of Energy provided by RM i to feed j
float E3[RM][Fd]=...; //high

//Decision variables
dvar float+ X[RM][T];
tuple RF{
string RM;
string Feed;
```

```
};
{RF} ij=...;
dvar float+ Y[<i,j> in ij, t in T];
dvar float+ I[RM][T];

dvar float+ Usage[Fd][T];
dvar float+ Amount[RM][Fd];
dvar float+ Y_UsedRM[RM][T];

dvar float+ ic[RM][T];

dexpr float PC1=sum(i in RM, t in T)(C1[i][t]*X[i][t]);
dexpr float PC2=sum(i in RM, t in T)(C2[i][t]*X[i][t]);
dexpr float PC3=sum(i in RM, t in T)(C3[i][t]*X[i][t]);

dexpr float IC=sum(i in RM, t in T)(H[i]*I[i][t]);

dexpr float Z1=PC1+IC;
dexpr float Z2=PC2+IC;
dexpr float Z3=PC3+IC;

dexpr float Z=w1*Z1+w2*Z2+w3*Z3;

//Objective function
minimize Z;

//Constraints:
subject to{

Con1:
forall(j in Fd, t in T){
Usage[j][t] == sum(i in RM)Y[<i,j>,t];
};
forall(i in RM, j in Fd){
Amount[i][j]== (sum(t in T)Y[<i,j>,t])/1000;
}
forall(i in RM, t in T){
Y_UsedRM[i][t] == sum(j in Fd)Y[<i,j>,t];
}
forall(i in RM, t in T){
ic[i][t] == H[i]*I[i][t];
};

Con2://Fuzzy Supply
forall(i in RM, t in T)
X[i][t] <= 0.5*(1-w)*S1[i][t] + w*S2[i][t] + 0.5*(1-w)*S3[i][t];

Con3://Fuzzy
Demand*******************************************************Y=D???
forall(j in Fd, t in T)
sum(i  in  RM)Y[<i,j>,t]  ==  0.5*(1-w)*D1[j][t]  +  w*D2[j][t]  +  0.5*(1-
w)*D3[j][t];

Con4://Inventory balance
forall(i in RM, t in T:t==1){
sum(j in Fd)Y[<i,j>,t] + I[i][t] == X[i][t];
```

```
};
forall(i in RM, t in T:t>=2){
sum(j in Fd)Y[<i,j>,t] + I[i][t] == X[i][t] + I[i][t-1];
};

Con5://Fuzzy Protein Provision
forall(j in Fd, t in T)
sum(i in RM)(P1[i][j]*Y[<i,j>,t]) >= PR[j]*D1[j][t];

forall(j in Fd, t in T)
sum(i in RM)(P2[i][j]*Y[<i,j>,t]) >= PR[j]*D2[j][t];

forall(j in Fd, t in T)
sum(i in RM)(P3[i][j]*Y[<i,j>,t]) >= PR[j]*D3[j][t];

Con6://Fuzzy Energy Provision
forall(j in Fd, t in T)
sum(i in RM)(E1[i][j]*Y[<i,j>,t]) >= ER[j]*D1[j][t];

forall(j in Fd, t in T)
sum(i in RM)(E2[i][j]*Y[<i,j>,t]) >= ER[j]*D2[j][t];

forall(j in Fd, t in T)
sum(i in RM)(E3[i][j]*Y[<i,j>,t]) >= ER[j]*D3[j][t];

Con7://Satisfy Lower Bound
forall(i in RM, j in Fd, t in T:t<=4)
sum(t   in   T:t<=4)Y[<i,j>,t]   >=   (L[i][j]/100)*sum(i   in   RM,   t   in
T:t<=4)Y[<i,j>,t];

forall(i in RM, j in Fd, t in T:t>=5)
Y[<i,j>,t] >= (L[i][j]/100)*sum(i in RM)Y[<i,j>,t];

Con8://Satisfy Upper Bound
forall(i in RM, j in Fd, t in T)
Y[<i,j>,t] <= (U[i][j]/100)*sum(i in RM)Y[<i,j>,t];

//Warehouse Capacity limits
Con9:
forall(t in T: t==1)
sum(i in RM)X[i][t] <= (k/12)*(0.5*(1-w)*sum(j in Fd, t in T)D1[j][t]
                                                +w*sum(j   in   Fd,   t   in
T)D2[j][t]
                                                +0.5*(1-w)*sum(j in Fd, t in
T)D3[j][t]);
forall(t in T: t>=2)
sum(i  in  RM)X[i][t]  +  sum(i  in  RM)I[i][t-1]  <=  (k/12)*(0.5*(1-w)*sum(j  in
Fd, t in T)D1[j][t]

               +w*sum(j in Fd, t in T)D2[j][t]

               +0.5*(1-w)*sum(j in Fd, t in T)D3[j][t]);

}
//Policies:
```

```
//Purchase all maize
Con10://All maize available will be purchased
forall(t in T)
X["Maize"][t] == 0.5*(1-w)*S1["Maize"][t]+w*S2["Maize"][t]+0.5*(1-w)*S3["Maize"][t];
}
//3:1
Con11:
forall(t in T)
X["Maize"][t] >= 3*X["WheatGrain"][t];
}
//2:1 RMP
Con12:
forall(t in T)
X["Maize"][t] >= 2*X["WheatGrain"][t];

}
//2:1 & 3:1 RMP
Con13://June-August
forall(t in T: t<=3)
X["Maize"][t] >= 2*X["WheatGrain"][t];

Con14://Sep-May
forall(t in T: t>=4)
X["Maize"][t] >= 3*X["WheatGrain"][t];
}
//3:1
Con15:
forall(t in T)
X["Maize"][t] >= 3*X["WheatGrain"][t];
}
SheetConnection sheet("Basecase.xlsx");

RM from SheetRead(sheet,"Set!a2:a10");
Fd from SheetRead(sheet,"Set!b2:b9");
ij from SheetRead(sheet,"Set!d1:e72");

H from SheetRead(sheet,"HoldingCost!b2:b10");
PR from SheetRead(sheet,"Requirement!b3:b10");
ER from SheetRead(sheet,"Requirement!c3:c10");
L from SheetRead(sheet,"MinMax!b2:i10");
U from SheetRead(sheet,"MinMax!b14:i22");

//Fuzzy parameters:
C1 from SheetRead(sheet,"C1!b3:m11");
C2 from SheetRead(sheet,"C2!b3:m11");
C3 from SheetRead(sheet,"C3!b3:m11");


S1 from SheetRead(sheet,"S1!b3:m11");
S2 from SheetRead(sheet,"S2!b3:m11");
S3 from SheetRead(sheet,"S3!b3:m11");
```

```
D1 from SheetRead(sheet,"D1!b3:m10");
D2 from SheetRead(sheet,"D2!b3:m10");
D3 from SheetRead(sheet,"D3!b3:m10");

P1 from SheetRead(sheet,"N1!b2:i10");
P2 from SheetRead(sheet,"N2!b2:i10");
P3 from SheetRead(sheet,"N3!b2:i10");

E1 from SheetRead(sheet,"N1!b14:i22");
E2 from SheetRead(sheet,"N2!b14:i22");
E3 from SheetRead(sheet,"N3!b14:i22");

X to SheetWrite(sheet,"X!b2:m10");
Y to SheetWrite(sheet,"Y!c2:n73");
I to SheetWrite(sheet,"I!b2:m10");

Usage to SheetWrite(sheet,"D2!b15:m22");
Amount to SheetWrite(sheet,"Analysis!k5:r13");
Y_UsedRM to SheetWrite(sheet,"Y_UsedRM!b2:m10");

ic to SheetWrite(sheet,"InvCost!b2:m10");

Z1 to SheetWrite(sheet,"Costs!f2");
Z2 to SheetWrite(sheet,"Costs!f3");
Z3 to SheetWrite(sheet,"Costs!f4");
//Z to SheetWrite(sheet,"Costs!d2");

PC1 to SheetWrite(sheet,"Costs!b2");
PC2 to SheetWrite(sheet,"Costs!b3");
PC3 to SheetWrite(sheet,"Costs!b4");

IC to SheetWrite(sheet,"Costs!c2");


//pc to SheetWrite(sheet,"PCost!b2:m10");
//PC to SheetWrite(sheet,"Costs!a2");
//TotalCost to SheetWrite(sheet,"Costs!c2");
```

BIOGRAPHY

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Publications	

Thy, N. N. A., Buddhakulsomsiri, J., & Parthanadee, P. (2020). A Mathematical Model for Optimizing Organic Feed Mix Problem. *Proceedings of 7th International Conference on Industrial Engineering and Applications (ICIEA)* (pp. 570-573). Bangkok: IEEE.