DTU Library

The Value of a General Increase in Slaughter Weight for Pigs

Kjærsgaard, Niels Christian

Publication date:
2008

Document Version
Publisher's PDF, also known as Version of record

The Value of a General Increase in Slaughter Weight for Pigs

Niels Kjærsgaard
Department of Management Engineering
Technical University of Denmark
2800 Lyngby
Denmark

March 31, 2008

Abstract

The pig industry is an important part of Danish economy with an export value in 2006 of more than DKK 28 billions [Danish Meat Association (2007)]. The competition is hard and increased feeding costs are affecting the farmer's profitability. Therefore it is important to optimize all aspects of Danish pig production, slaughtering processes and delivery.

There have been varying opinions within the industry concerning an improved profit for the slaughterhouses and the farmers when increasing the slaughter weight. The argument for an increased slaughter weight is based on the fact that some of the costs at the slaughterhouses and at the farmers are unit costs variable to the number of pigs produced and for that reason it would be interesting if the slaughter weight was increased. If the slaughter weight was increased and the number of items produced almost unchanged, the costs per kg produced meat would decrease. The savings in costs should be compared to the possible decrease in the average sales price. These considerations are continuously taking place in the industry, but some more accurate tools to find the economic consequences are desired.

This paper concerns the aspects of optimization at the slaughterhouses and farmers, especially regarding estimation of the economic consequences of an increased slaughter weight.

Operations Research methods are used to solve this important practical problem for the industry.

The model is a Mixed Integer Programming (MIP) model applied on four different weight scenarios, namely the current slaughter weight as well as increases in the slaughter weight of 5, 10 and 15 kg respectively. The model set up in this paper consists of 17 different products and four alternative uses of each pig, but the model can easily be changed to include more products and alternative uses.

The model is illustrated in this paper using test data consisting of slaughtering data for 43,949 pigs slaughtered at one of the Danish slaughterhouses. Increased slaughter weight results in an increased turnover, but also in a decrease in the average price per kg. For a weight increase of 5 kg the average price per kg decreases by DKK 0.241. The similar decrease in average prices for weight increases of 10 and 15 kg is DKK 0.492 and DKK 0.706 respectively. This should be compared to savings at the slaughterhouses as well at the farmers, which previously have been estimated to approximately DKK 0.25 for each increase in slaughter weight of 5 kg.

The main conclusion is that even relatively simple optimization models can be used to improve the basis of the slaughterhouses considerably for making decisions regarding the value of increased slaughter weight. Prices may vary over time as the market situation changes continuously. In order to make the results trustworthy and reliable for decision making, it is essential that prices, costs and product yields for different products are estimated carefully. Even though the computations are made for illustrative purposes, the figures indicate that other options than increased slaughter weight may be more profitable to pursue.

1 Background

The pig industry is important for Danish economy, with a production in 2006 of more than 25 million pigs in Denmark. Approximately 90% of the meat was exported and had an export value of DKK 28.8 billion [Danish Meat Association (2007)].

Competition is hard, and increased feeding costs have substantial impact on the farmers' profitability. There is a substantial pressure on the slaughterhouses to provide increased payment to the farmers.

Therefore it is becoming more and more important that Danish farmers and slaughterhouses continue to optimize their production and slaughtering processes. This paper concerns the aspects of the optimization at the slaughterhouses, especially the economic consequences of increased slaughter weight.

Danish slaughterhouses can quickly change important characteristics such as meat content and the weight of the pigs being slaughtered by changing the payments to the farmers.

There have been varying opinions within the industry concerning an improved profit for the slaughterhouses and the farmers when increasing the slaughter weight. The argument for an increased slaughter weight is based on the fact that some of the costs at the slaughterhouses are unit costs variable to the number of pigs slaughtered and for that reason it would be interesting if the slaughter weight was increased. If the slaughter weight was increased and the number of items produced almost unchanged, the costs per kg produced meat would decrease. The savings in costs should be compared to the possible decrease in the average sales price. These considerations are continuously taking place in the industry, but some more accurate tools to find the economic consequences are desired. This paper concerns the use of Operations Research to solve this practical problem of major importance for the industry.

2 Literature survey

The literature regarding optimized raw material use at the slaughterhouses has been addressed in the paper "The Value of Improved Measurements in a Pig Slaughterhouse" [Kjærsgaard, N. (2008a)] but is repeated here for convenience.

The amount of literature addressing improved or optimized raw material use in the food industry is substantial. However, the main part of the contributions is related to different aspects regarding either optimization of meat quality or different production processes. Examples of this are optimization of the industrial thermal sterilization of canned foods [Garcia, M. et. al. (2006)] and pigs stunning optimization [Dupuis, P. et. al. (2004)]. These types of optimizations are not relevant for this project as they are either based on statistical analysis without optimization of a mathematical model or the mathematical models are very different from the models, which are used in this Ph.D. project regarding optimization of the raw material use at the slaughterhouses.

Within the pork industry relatively few contributions have been found regarding optimization based on operations research methods. In the paper "Location of slaughterhouses under economies of scale" [Broek et. al. (2006)] optimization is used to investigate the savings potential of reducing the number of slaughterhouses in Norway and investing in additional capacity in the remaining facilities in order to obtain economies of scale. Another facility location problem is described in the paper “The impact of changes in livestock supply on the optimum number, size and location of slaughterhouses in East Macedonia” [Kamenidis, C. & Sorensen, V. (1978)]. In the paper ”Economic optimization of pork production – marketing chains. II. Modelling outcome” [Ouden et. al. (1996)] are using Dynamic Linear programming to evaluate the development of pork chain concepts that also takes animal welfare into consideration. Kure in his Ph.D. thesis “Marketing Management Support in Slaughter Pig Production” [Kure, H. (1997)] uses Dynamic Programming to solve parts of the “slaughter pig marketing management problem”, which regards how the farmers should select and market their pigs to the slaughterhouses.

The above mentioned four examples of optimization problems within the pork industry are all somewhat different from the problem of optimizing the raw material use at the slaughterhouses. More similar problems have been found in the following contributions:

In 1990-1992 a project regarding optimization of the raw material use at the slaughterhouses was performed as a cooperation between Danish Meat Research Institute and the Royal Veterinary and Agricultural University (now the Faculty of Life Sciences at University of Copenhagen). Several reports were made:

A Linear Programming (LP) model for production planning and control for the hog slaughterhouses was developed and reported in [Rasmussen, S. & Thomsen, M. (1991)] and [Rasmussen, S. (1992)]. The model is a 2-stage model. First stage concerns a planning horizon of 3 months and the second stage one weeks day to day planning. In [Fertin, C. (1992)] the long term planning model (stage 1) is validated.
In his Ph.D. thesis [Fertin [1995)] Fertin describes and further develops and validates the model.

There has been searched for literature in other food related industries, e.g. poultry and beef slaughterhouses and the fish industry, but no relevant literature has been found.

Other industries have similar problems as the slaughterhouses regarding its raw material use. An example is the refineries, but unlike the slaughterhouses the refineries have the option of blending different qualities in order to change the quality characteristics of the products. Another example is the lumber and wood industry. A few papers of the product mix problem within the wood industry have been identified. In the paper “An Optimization-Based Decision Support System for a Product Mix Problem” [Roy et. al. (1982)] an LP-model has been used to solve a plywood product mix problem for Ponderosa Industrial in Mexico.

Even though literature within food optimization is substantial, the main part of the contributions are related to optimization based on e.g. statistical analysis without optimization of a mathematical model. Other models are very different from the models used in this Ph.D. project. Except for the contributions from the Royal Veterinary and Agricultural University and the Danish Meat Research Institute not much literature of relevance for the Ph.D. project has been identified.

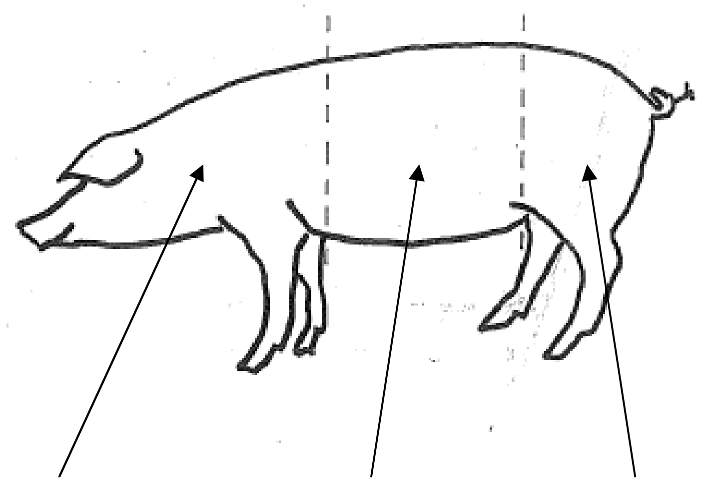
3 The Model

The purpose of the model is to investigate the economic consequences of a general increase in slaughter weight. The model has been used on four different weight scenarios, namely for the current slaughter weight as well as for increases in the slaughter weight of 5, 10 and 15 kg respectively. Benefits are found by comparing the optimal solution for the current slaughter weight with the optimal solution at the increased levels.

3.1 Description of the Model

In the experiments we use the actual slaughtering data from 43,949 pigs slaughtered at one of the Danish slaughterhouses. For each pig the registered fat layer (in mm) and the actual slaughter weight are used. In the computations, the registered fat layer is considered the true value, and the effect of a general increase in slaughter weight is estimated for each of the four weight scenarios. In general there is coherence between the slaughter weight and the size of the fat layer. When the slaughter weight is increased by 1 kg, the fat layer is increased by approx. 0.16 mm. This coherence is found using regression analysis. See the chapter "Estimation of model parameters" for further information regarding this issue.

The model has its basis in different alternative uses of the pigs. Each alternative use consists of a "package" of products for the specific part (the fore end, the middle piece and the ham) and can be seen in Figure 1 below. In the experiments, the back and the ham have two alternative uses each and the fore end has one. In total there are four different alternative uses of each pig and 17 different main products. The weight of each product is estimated for each pig at each of the four weight scenarios used in the computations.



Fore-end

Alternative 1
P_Schoulder
P_Neck
P_CutOff1
P_Sundry1

Middle

Alternative 1
P_Backs (with bones)
P_Breast1
P_CutOff2
P_Sundry2

Alternative 2
P_Backs (boneless)
P_Breast2
P_CutOff3
P_Sundry3

Ham

Alternative 1
P_Ham
P_Sundry4

Alternative 2
P_Ham (boneless)
P_CutOff5
P_Sundry5

Figure 1. Alternative uses of the pigs.

Some raw materials (pigs) are better suited for some products than others. This is taken into consideration when increasing or decreasing the price for some products depending on the level of the fat layer. In the model, this is done by splitting the pricing in two different contributions:

1. A fixed price per kg for the given product

   and

2. A price coefficient, which stipulates how much the price will decrease if the fat layer increases by 1 mm.

For two of the products there are a few special conditions which have to apply for the raw materials to be used for these products:

- The ham product P_Ham can only be produced if the fat layer does not exceed 14 mm

  and

- The breast product P_Breast2 can only be produced if it does not exceed a weight of 4 kg.

The products P_CutOff (1, 2, 3, 5) consist of meat cut-off in connection with production of the main products and products P_Sundry (1-5) consist of fat, bones, rind etc.

The price for each product is calculated at different weight scenarios based on its estimated weight and fat layer. The best alternative use of each pig is found by optimization, and the total obtainable price for the 43,949 pigs are summed. The same computations are obtained at each of the different weight scenarios. The value of a general increase in slaughter weight is then found as the difference between the profit for the optimal solutions after and before the weight increase.

3.2 Mathematical formulation of the Model

We have a set of carcasses $\mathscr{I}$={1…,I}. Each carcass can be used to produce a set of different products $\mathscr{J}$={1,…,J}. Finally we have a set of different weight scenarios $\mathscr{K}$={1,…,K}. The decision variable $x_{i,j,k}$ is a binary variable with the value 1 if pig i is used to produce product j in weight scenario k and 0 otherwise. The problem is to find the optimal utilization of each carcass at each weight scenario and the total profit for the optimal solution for each weight scenario:

The objective function:

1) $$Maximize\ Z = \sum_{i,j,k} \left(\Pr ice_j + \Pr iceCoeff_j \cdot FatLayer_{i,k}\right) \cdot \Pr odWeight_{i,j,k} \cdot x_{i,j,k}$$

Subject to:

2) $x_{i,P\_Breast2,k} \cdot ProdWeight_{P\_Breast2,k} \leq 4$

3) $x_{i,P\_Ham,k} \cdot FatLayer_{i,k} \leq 14$

4) $x_{i,P\_Schoulder,k} = x_{i,P\_Neck,k} \quad \forall\ i \in \mathcal{I},\ k \in \mathcal{K}$

5) $x_{i,P\_Neck,k} = x_{i,P\_CutOff1,k} \quad \forall\ i \in \mathcal{I},\ k \in \mathcal{K}$

6) $x_{i,P\_CutOff1,k} = x_{i,P\_Sundry1,k} \quad \forall\ i \in \mathcal{I},\ k \in \mathcal{K}$

7) $x_{i,P\_Backs\ (with\ bones),k} = x_{i,P\_Breast1,k} \quad \forall\ i \in \mathcal{I},\ k \in \mathcal{K}$

8) $x_{i,P\_Breast1,k} = x_{i,P\_CutOff2,k} \quad \forall\ i \in \mathcal{I},\ k \in \mathcal{K}$

9) $x_{i,P\_CutOff2,k} = x_{i,P\_Sundry2,k} \quad \forall\ i \in \mathcal{I},\ k \in \mathcal{K}$

10) $x_{i,P\_Backs\ (boneless),k} = x_{i,P\_Breast2,k} \quad \forall\ i \in \mathcal{I},\ k \in \mathcal{K}$

11) $x_{i,P\_Breast2,k} = x_{i,P\_CutOff3,k} \quad \forall\ i \in \mathcal{I},\ k \in \mathcal{K}$

12) $x_{i,P\_CutOff3,k} = x_{i,P\_Sundry3,k} \quad \forall\ i \in \mathcal{I},\ k \in \mathcal{K}$

13) $x_{i,P\_Ham,k} = x_{i,P\_Sundry4,k} \quad \forall\ i \in \mathcal{I},\ k \in \mathcal{K}$

14) $x_{i,P\_Ham\ (boneless),k} = x_{i,P\_CutOff5,k} \quad \forall\ i \in \mathcal{I},\ k \in \mathcal{K}$

15) $x_{i,P\_CutOff5,k} = x_{i,P\_Sundry5,k} \quad \forall\ i \in \mathcal{I}, \cdots k \in \mathcal{K}$

16) $x_{i,P\_Backs\ (with\ bones),k} + x_{i,P\_Backs\ (boneless),k} = 1 \quad \forall\ i \in \mathcal{I},\ k \in \mathcal{K}$

17) $x_{i,P\_Ham,k} + x_{i,P\_Ham\ (boneless),k} = 1 \quad \forall\ i \in \mathcal{I},\ k \in \mathcal{K}$

18) $x_{i,j,k} = \begin{cases} if\ \ production: & 1 \\ else: & 0 \end{cases} \quad \forall\ i \in \mathcal{I},\ j \in \mathcal{J},\ k \in \mathcal{K}$

Indices:
i: pig i (pig no. 1 to 43,949)
j: product j (17 different products, see figure 1)
k: weight increase (4 scenarios with current weight and weight increases of 5, 10 and 15 kg)

Decision variables:
$x_{i,j,k}$: decision variable with value 1 if product j is produced of pig i at weight scenario k, otherwise 0.

Parameters:
PigWeight (i): slaughter weight of pig i
ProdWeight (i, j): weight of product j produced from pig i

FatLayer (i): layer of fat (in mm) for pig i
Price(j): price per kg (in DKK) for product j
PriceCoeff(j): price coefficient for product j (price increase in DKK when layer decreases by 1 mm)

The objective function (1) is in fact a "dummy" function, which optimizes the sum of the optimal solutions for all four different weight scenarios. By finding the optimal solution for the dummy function, the optimal solution for each of the four weight scenarios are found at the same time, as there is no interconnection between the four scenarios.

Constraints no. 2 and 3 control that the product P_Breast2 only can be produced if the product does not exceed a weight of 4 kg and product P_Ham only if the fat layer does not exceed 14 mm.

The slaughterhouses have some constraints regarding the products produced. When the slaughterhouse decides to use a carcass to produce one product other specific products often have to be produced as well. Constraints 4-15 ensures that when an alternative use of the pig is chosen, a whole package of products is chosen. For instance constraint 4 controls that if P_Schoulder is produced then P_Neck is produced as well. If this is the case, constraints 5 and 6 control that also P_CutOff1 and P_Sundry1 are produced as well.

Constraints 16 and 17 ensure, that the back and the ham only can be used for one alternative at a time and equation 18 that $x_{i,j,k}$ is a binary variable keeping track on whether there is production or not.

3.3 Estimation of model parameters

In the following, estimation of the different model parameters used as input to the model will be described briefly.

3.3.1 Fat layer coefficient

The fat layer coefficient stating how much the fat layer is increased when the slaughter weight is increased by 1 kg has been estimated to 0.1648 and has been found through linear regression analysis. See the chapter "Sensitivity analysis" for further information regarding the coefficients effect on the results.

3.3.2 *Fat layer*

The fat layer is estimated based on the actually registered fat layer for each pig with the addition of a contribution as a consequence of the increased weight for weight scenario k.

Fat layer (in mm)$_{i,k}$ = registered fat layer$_{i,k=0}$ + 0.1648 * weight increase$_{k}$

By using the actually registered fat layer as a basis, the fat layer realistically reflects the measuring noise.

3.3.3 *Slaughter weight*

The actually registered slaughter weight of each pig is used and for the different weight scenarios, 5, 10 and 15 kg respectively have been added.

3.3.4 *Weight of products*

The weight of the 17 products is estimated at different weight scenarios based on the estimated fat layer and the slaughter weight.

The coefficients used are found by linear regression analysis with data from a previous project (project "Europe Pig" [Danish Meat Research Institute (1996)]), where the connection between increased slaughter weight and product yields was found.

4 Results

The economic consequences of a general increase in slaughter weight of pigs produced in Denmark are found by performing optimizations at different weight scenarios. The consequences are presented as the difference between the profit from different weight scenarios and the profit from the current level of slaughter weight.

The following four weight scenarios have been investigated:

- current level of slaughter weight

- general increase in slaughter weight by 5 kg
- general increase in slaughter weight by 10 kg
- general increase in slaughter weight by 15 kg

For each weight scenario the optimal solution is found and the profit hereof computed. The profit for each weight scenario and the effect of increased slaughter weight can be seen in Table 1 below:

	Current weight	Plus 5 kg	Plus 10 kg	Plus 15 kg
Profit in DKK	38,243,300	39,678,630	40,967,470	42,298,690
Profit improvement				
Production in kg	3,576,982	3,796,727	4,016,472	4,236,217
Average price per kg	10.692	10.451	10.200	9.985
Change in average net price		- 0.241	- 0.492	- 0.706

Table 1. Profit and change in average net price at the different weight scenarios.

There is a natural variation in prices from one week to another. As the market situation changes continuously it has not always been possible to gain access to the latest prices, but information of typical prevailing prices was received from the slaughterhouses. Before using the computations as actual decision support a price and cost survey should be performed.

It can be seen that the profit increases by DKK 1,435,329 if the slaughter weight is increased by 5 kg. However, the production volume increases by 219,745 kg, so the average profit per kg decreases by DKK 0.241. For the scenarios with weight increases of 10 and 15 kg the average prices obtained per kg decreases by DKK 0.492 and DKK 0.706 respectively.

Some of the costs at the slaughterhouses as well as at the farmers are, however, either fixed or variable according to the number of pigs produced instead of to the production in terms of weight. Therefore, the decrease in average prices should be compared to the cost savings in the slaughterhouses and at the farmers. These savings have previously been estimated to approximately DKK 0.15 [Mønsted, K. (2006)] and DKK 0.10 per kg respectively for each increase in slaughter weight by 5 kg.

Based on the test data, the model shows that the industry could gain some, however small, net cost savings by increasing the slaughter weight. If the number of pigs produced is the same as today, it might to some extent require additional investments in warehouse facilities at the slaughterhouses as well as capacity increases at the farmers. Another problem is whether the customers will accept the heavier products or not. All in all, the figures indicate that other options than increased slaughter weight may be more profitable to pursue.

The model has 2,812,736 constraints and 3,515,920 variables and was solved to optimality in 545 seconds in total for all four weight scenarios, which is considered a satisfactory time. See chapter 4.2 [Kjærsgaard, N. (2008e)] in the thesis for more information regarding solution time.

5 Sensitivity Analysis

As mentioned previously, the fat layer will generally increase when the slaughter weight increases. In connection with the computations in this paper it has been assumed that the fat level in general will increase by 0.1648 mm when the slaughter weight increases by 1 kg. In Table 2 below the sensitivity of the change in average price can be seen regarding changes in this coefficient.

Changes in fat layer coefficient		Plus 5 kg	Plus 10 kg	Plus 15 kg
Base	(0.1648)	- 0.241	- 0.492	- 0.706
Plus 0.01	(0.1748)	- 0.249	- 0.507	- 0.727
Minus 0.01	(0.1548)	- 0.232	- 0.476	- 0.686
Plus 0.05	(0.2148)	- 0.283	- 0.566	- 0.805
Minus 0.05	(0.1048)	- 0.197	- 0.413	- 0.602

Table 2. Changes in average net price depending on fat layer coefficient.

Table 2 above shows that a change in the coefficient by plus/minus 0.01 results in an additional change in the average net price of between DKK 0.008 – 0.009 per kg when the slaughter weight increases by 5 kg. For increases in the slaughter weight of 10 and 15 kg, the additional change in the average price is DKK 0.015 and DKK 0.020 per kg respectively. If the coefficient changes by plus/minus 0.05, the additional change in the average net price will instead be between DKK 0.024 – 0.027 for a weight increase of 5 kg, and DKK 0.040 – 0.044 and DKK 0.047 – 0.054 respectively for weight increases of 10 and 15 kg.

For larger changes in the fat layer coefficient a considerable effect in the changes of the average net price can be seen. It should, however, be noticed that a change in the fat layer coefficient by plus/minus 0.05 is considered quite extreme, and it should be possible to estimate it much more accurately. Further studies should be made to examine if there are even better ways than linear regression analysis to describe the connection between slaughter weight and the fat layer.

It is very important that correct net prices are used and that they truly reflect the prices and costs of different products depending on the quality of the raw materials. There are considerable uncertainties regarding the $PriceCoeff_j$ which is the coefficient describing how much the price in DKK per kg changes when the fat layer of the pig increases by 1 mm. Table 3 below describes the changes in the average net price as a consequence of increased slaughter weight when different price coefficients are applied.

Changes in price coefficient	Plus 5 kg	Plus 10 kg	Plus 15 kg
Base - current price coeffifients	- 0.241	- 0.492	- 0.706
Price coefficients halved	- 0.205	- 0.422	- 0.604
Price coefficients incr. 50%	- 0.277	- 0.562	- 0.810
Price coefficients incr. 100%	- 0.313	- 0.633	- 0.914

Table 3. Changes in average net price due to increased slaughter weight at different levels of price coefficients.

Table 3 shows that the changes in the average net prices are significant and might even influence on whether or not it will be profitable for the industry to make a general increase of the slaughter weight. It is therefore important that the net prices, including the price coefficients, represent a fair view of the actual costs and prices which the slaughterhouses can obtain for its products.

6 Discussion

The purpose of the current paper has been to illustrate how Operations Research can be applied to improve estimations of the economic consequences of a general increase in slaughter weight. Prices vary from one week to another and are here only used for illustration of the model. In order to use the model for actual decision making the prices and cost as well as product yields and how all these factors are influenced by changes in the slaughter weight should be further studied in cooperation with Danish slaughterhouses.

The model can be improved by:

- Using more products and product alternatives. The model should ideally use all important products, and all important product alternatives should be determined. The product alternatives can be determined for each part individually (front end, middle piece and ham) requiring fewer product alternatives. For the relatively few products where parting in three influences possible products, the possible product alternatives should be determined separately as product yields may differ.

- Estimation of product yields should be updated. The weight of each product should be estimated as well as how much the weight changes depending on the measured fat layer and slaughter weight. In these cases where the product yields are influenced by which product alternatives it is part of, separate products should be established.

- Different measures of the fat layer should be used depending on which part (i.e. fore end, middle piece or ham) of the pig is used for the specific product. The model uses only one general measure of the fat layer for the pig, but individual measures for different parts can be used instead.

- Prices and cost, i.e. net prices per kg as well as changes in the net prices according to increases/decreases in the fat layer should be updated for each product.

- Introducing constraints regarding minimum and maximum sale volumes of different products would make the model even more realistic.

Especially regarding net prices and product yields it is very important that the data input describes the actual value of different products as well as possible. For that reason further investigations should be made into price and yield functions to clarify whether linear functions are the best illustrations or better alternatives could be found.

When estimating the slaughter weight after a general weight increase it was assumed that the slaughter weight of each pig is increased by the same amount (Figure 2). The increase has been 5, 10 and 15 kg for the different weight scenarios. In real life this may not exactly be the case as the distribution to some degree may be extended, meaning that the heavy pigs in average increases with more than 5 kg and the smaller pigs with less than 5 kg. See figure 2 and 3 below for an illustration of this.

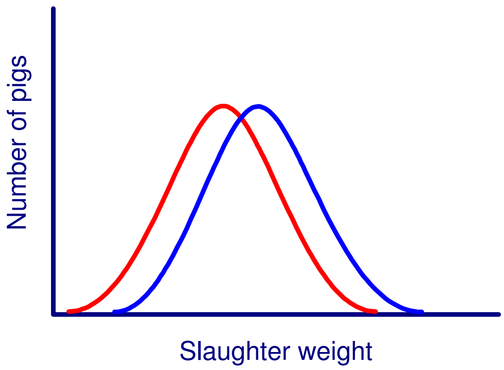


Figure 2. Distribution of weight

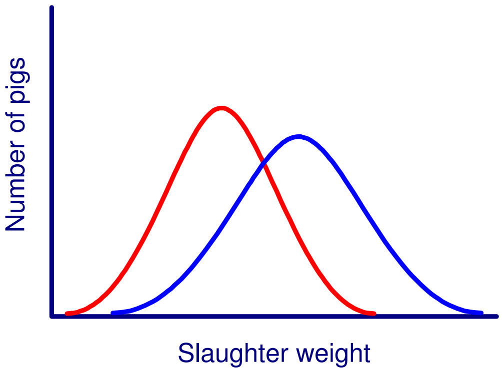


Figure 3. Distribution of weight

Figure 2 and 3 are for illustrative purposes only. The red curve represents the current distribution of pigs on slaughter weight and the blue curve the future state with increased slaughter weight. In real life the distribution is not normal, but skewed a bit to the left. Figure 2 describes the distribution of pigs when the slaughter weights of all pigs are increased by the same amount as assumed in the computations in this paper. Figure 3 describes how the distribution may look if the slaughter weight of the heavier pigs increases with more than 5 kg and with less for the smaller pigs. However, it is likely that the slaughterhouses will have a slimmer contribution, which can be obtained by changes in the payment structure to the farmers. This is the reason for using the assumption that all pigs will be increased with the same amount in the computations.

7 Conclusion

Determining the optimal slaughter weight for pigs for slaughter is one of the important decisions for Danish slaughterhouses and the farmers, and it is important that the decision is made on as solid a basis as possible. Therefore, development of tools to improve the accuracy of such calculations is considered an important area. The purpose of this paper is to provide a first step to such an improvement by establishing a model using only few products and product alternatives.

The model has four alternative uses for each pig and 17 different products in total, but the model can easily be changed to include more products and alternative uses. The computations in this paper are for illustrative purposes only, and before making decisions based on the model it should include all important products and product alternatives. Furthermore, it is essential that prices, costs and product yields for the different products are estimated carefully. It should be investigated whether or not there are even better alternatives to describe the price and yields functions than linear functions.

The model can be made even more realistic by introducing constraints for the minimum and maximum sale of different products.

The main conclusion is that operations research methods and even relatively simple models can be used to improve the slaughterhouses basis for decision making regarding increased slaughter weight. Prices may vary over time, and before using the model for actual decision support more products and product alternatives should be included and a price and cost study should be obtained.

An increased slaughter weight results in an increased turnover, but as the volume sold increases even more, the average price per kg falls. The average price decreases with DKK 0.241 for a weight increase of 5 kg and DKK 0.492 and DKK 0.706 for weight increases of 10 and 15 kg respectively. However, some of the costs at the slaughterhouses and at the farmers are fixed or variable according to the number of pigs being produced and not to the weight of the pigs. An increased slaughter weight results in savings at the slaughterhouses as well at the farmers and has previously been estimated to approx. DKK 0.15 and DKK 0.10 respectively, totalling approx. DKK 0.25 for each increase in the slaughter weight of 5 kg. In these circumstances, potential savings are almost of the same size as the decrease in average prices, and the profits are consequently not improved significantly.

The sensitivity analysis shows that large changes in the fat layer coefficient have a considerable effect on the changes in the average net price and can easily change whether a decision is profitable or not. This is especially the case for decisions close to break-even. Further studies should be made to analyse how well linear functions describe the connection between slaughter weight and the fat layer.

These computations are based on the assumption that the number of pigs being slaughtered is not affected by the increased slaughter weight. To some extent, however, it might require additional investments at the slaughterhouses and at the farmers to handle larger pigs. Another problem is whether the customers will accept the heavier products or not. All in all the figures computed indicate that even though the prices received from the slaughterhouses are for illustrative purposes other options than increased slaughter weight may be more profitable to pursue.

Bibliography

Broek et. al. (2006). Location of slaughterhouses under economies of scale. European Journal of Operational Research 175 (2006 740-750).

Danish Meat Association (2007). Danske Slagterier. Statistics 2006 – pigs.

Danish Meat Research Institute (1996). Project Europe Pig – Production adaptation experiments (in Danish). Working Paper 03.457/04 – confidential

Dupuis, P. et. al. (2004). Pigs Stunning Optimisation. Instrumentation and Measurement Technology Conference, Como, Italy.

Fertin, C. (1992). Validation of long term planning model for optimization of the raw material use at pig slaughterhouses (in Danish). The Royal Veterinary and Agricultural University, Copenhagen, Denmark.

Fertin, C. (1995). The use of a multi-Periodic LP-Model as Basis for a Decision Support System for Pig Slaughterhouses (in Danish). Ph.D. Thesis (Lic. 1239), The Royal Veterinary and Agricultural University, Copenhagen, Denmark.

Garcia, M. (2006). Computing optimal operating policies for the food industry. Journal of Food Engineering 74 (2006 13-23.

Hillier, F & Lieberman, G. (2001). Introduction to Operations Research. Seventh Edition. McGraw-Hill International Editions.

Kamenidis, C. & Sorensen, V. (1978). European Review of Agricultural Econimics (1978-5 143-158).

Kjærsgaard, N. (2008a). The Value of Improved Measurements in a Pig Slaughterhouse. Technical Report, Department of Informatics and Mathematical Modeling, Technical University of Denmark.

Kjærsgaard, N. (2008b). The Value of a General Increase in Slaughter Weight for Pigs. Technical Report, Department of Informatics and Mathematical Modeling, Technical University of Denmark.

Kjærsgaard, N. (2008c). Limitations in Production and Stock and their effect on the Profitability of the Slaughterhouses. Technical Report, Department of Informatics and Mathematical Modeling, Technical University of Denmark.

Kjærsgaard, N. (2008d). Evaluating Different Sorting Criteria and Strategies using Mathematical Programming. Technical Report, Department of Informatics and Mathematical Modeling, Technical University of Denmark.

Kjærsgaard, N. (2008e). Optimization of the Raw Material Use at the Danish Slaugnterhouses. Ph.D. thesis. Department of Informatics and Mathematical Modeling, Technical University of Denmark.

Kure, H. (1997). Marketing Management Support in Slaughter Pig Production. Ph.D. Thesis (Dina Research Rapport No. 57), The Royal Veterinary and Agricultural University, Copenhagen, Denmark.

Mønsted, K. (2006) Slaughterhouse costs at increased slaughter weight (in Danish). Internal presentation. Danish Meat Research Institute.

Ouden et. al. (1996). Economic optimization of pork production – marketing chains. II. Modelling outcome. Livestock Productioin Science 48 (1997 39-50).

Rasmussen, S. & Thomsen, M. (1991). A Model for Optimizing of the Raw Material Use at Pig Slaughterhouses. The Royal Veterinary and Agricultural University, Copenhagen, Denmark.

Rasmussen, S. (1992), The use of a multi-period LP-model as the core of a Decision Support System for a hog slaughterhouse. The Royal Veterinary and Agricultural University, Copenhagen, Denmark.

Roy et. al. (1982). An Optimization-Based Decision Support System for a Product Mix Problem. The Institute of Management Sciences, vol. 12, no. 2, April 1982.

Wolsey, L. (1998). Integer Programming. John Wiley & Sons, Inc.

Appendix 1 – GAMS code

```
* CanneryTransport.gms
*
* CanneryTransport.gms
*
$eolcom //
option iterlim=999999999;     // avoid limit on iterations
option reslim=300;            // timelimit for solver in sec.
option optcr=0.0;             // gap tolerance
option solprint=OFF;          // include solution print in .lst file
option limrow=100;            // limit number of rows in .lst file
option limcol=100;            // limit number of columns in .lst file
//-------------------------------------------------------------------


SETS   i   Pigs i     /p1*p43949/
       j   Products   /P_Schoulder, P_Neck, P_Backs (with bones), P_Breast1,
                       P_Backs (boneless), P_Breast2, P_Ham, P_Ham (boneless),
                       P_CutOff1, P_CutOff2, P_CutOff3, P_CutOff5, P_Sundry1,
                       P_Sundry2, P_Sundry3, P_Sundry4, P_Sundry5, P_Tenderloin,
                       P_head, H_8201  /
       s(j) Products sold    / P_Schoulder, P_Neck, P_Backs (with bones),
                               P_Breast1, P_Backs (boneless), P_Breast2, P_Ham,
                               P_Ham (boneless), P_CutOff1, P_CutOff2,
                               P_CutOff3, P_CutOff5, P_Sundry1, P_Sundry2,
                               P_Sundry3, P_Sundry4, P_Sundry5, P_Tenderloin,
                               P_Head /
       k   weight increase  /  w_0, w_5, w_10, w_15 /;



PARAMETER
  Price(j) Price per kg for products j
           /
             P_Schoulder           12.00
             P_Neck                13.00
             P_Backs (with bones)  18.00
             P_Breast1             13.00
             P_Backs (boneless)    25.00
             P_Breast2             17.00
             P_Ham                 15.00
             P_Ham (boneless)      18.00
             P_CutOff1              9.00
             P_CutOff2              9.00
             P_CutOff3              9.00
             P_CutOff5              9.00
             P_Sundry1              3.00
             P_Sundry2              3.00
             P_Sundry3              3.00
             P_Sundry4              3.00
             P_Sundry5              3.00
             P_Tenderloin          30.00
```

```
               P_Head                 3.00
               H_8201                 0.00
                                               /

PriceCoeff(j) Price Coefficient (in DKK) for product j for an increase of layer
of fat (in mm)
         /     P_Schoulder            0.00
               P_Neck                 0.00
               P_Backs (with bones)  -0.20
               P_Breast1             -0.20
               P_Backs (boneless)    -0.20
               P_Breast2             -0.20
               P_Ham                 -0.20
               P_Ham (boneless)      -0.20
               P_CutOff1             -0.10
               P_CutOff2             -0.10
               P_CutOff3             -0.10
               P_CutOff5             -0.10
               P_Sundry1              0.00
               P_Sundry2              0.00
               P_Sundry3              0.00
               P_Sundry4              0.00
               P_Sundry5              0.00
               P_Tenderloin           0.00
               P_Head                 0.00
               H_8201                 0.00
                                                /


          ProdWeightCon(j) Product weight constant for product j
         /     P_Schoulder             0.00000
               P_Neck                  0.00000
               P_Backs (with bones)   10.77058
               P_Breast1               2.00642
               P_Backs (boneless)      0.46036
               P_Breast2               2.00642
               P_Ham                   0.00000
               P_Ham (boneless)       -1.11490
               P_CutOff1               0.00000
               P_CutOff2               0.00000
               P_CutOff3               0.00000
               P_CutOff5               0.00000
               P_Sundry1              -1.95414
               P_Sundry2             -14.54192
               P_Sundry3               0.00000
               P_Sundry4               0.00000
               P_Sundry5               0.00000
               P_Tenderloin            1.20000
               P_Head                  0.00000
               H_8201                 -1.58570
                                                 /
```

```
ProdWeightFat(j) Product weight fat dependend coefficient for product j
         /     P_Schoulder           -0.06938
               P_Neck                -0.04096
               P_Backs (with bones)  -0.01662
               P_Breast1              0.04284
               P_Backs (boneless)    -0.08124
               P_Breast2              0.04284
               P_Ham                 -0.10204
               P_Ham (boneless)      -0.19054
               P_CutOff1             -0.00596
               P_CutOff2             -0.00596
               P_CutOff3             -0.00596
               P_CutOff5             -0.00596
               P_Sundry1              0.07922
               P_Sundry2              0.11178
               P_Sundry3              0.00000
               P_Sundry4              0.00000
               P_Sundry5              0.00000
               P_Tenderloin           0.00000
               P_Head                 0.00000
               H_8201                -0.10160
                                                  /

ProdWeightWeight(j) Product weight slaughtering weight dependent coefficient for
         product j
         /     P_Schoulder            0.10726
               P_Neck                 0.07282
               P_Backs (with bones)   0.01354
               P_Breast1              0.06002
               P_Backs (boneless)     0.08666
               P_Breast2              0.06002
               P_Ham                  0.27632
               P_Ham (boneless)       0.22874
               P_CutOff1              0.00834
               P_CutOff2              0.00834
               P_CutOff3              0.00834
               P_CutOff5              0.00834
               P_Sundry1              0.13368
               P_Sundry2              0.24410
               P_Sundry3              0.00000
               P_Sundry4              0.00000
               P_Sundry5              0.00000
               P_Tenderloin           0.00000
               P_Head                 0.00000
               H_8201                 0.29790
                                                  / ;


$Include FatLayer.txt
$Include PigWeight.txt


Parameter ProdWeight(j,i,k) Weight of product j from pig i at weight increase k
;
```

```
ProdWeight(j,i,k) = ProdWeightCon(j) + ProdWeightFat(j)*FatLayer(i,k)
       + ProdWeightWeight(j)*PigWeight(i,k) ;


ProdWeight('P_Sundry3',i,k) = ProdWeight('P_Backs (with bones)',i,k)
      + ProdWeight('P_Breast1',i,k)
      + ProdWeight('P_CutOff2',i,k)
                     + ProdWeight('P_Sundry2',i,k)
      - ProdWeight('P_Backs (boneless)',i,k)
      - ProdWeight('P_Breast2',i,k)
     - ProdWeight('P_CutOff3',i,k) ;

ProdWeight('P_Sundry4',i,k) = ProdWeight('H_8201',i,k) - ProdWeight('P_Ham',i,k)
;

ProdWeight('P_Sundry5',i,k) = ProdWeight('H_8201',i,k)
      - ProdWeight('P_Ham (boneless)',i,k)
      - ProdWeight('P_CutOff5',i,k) ;

ProdWeight('P_Head',i,k) = PigWeight(i,k) - ProdWeight('P_Schoulder',i,k)
      - ProdWeight('P_Neck',i,k)
      - ProdWeight('P_Backs (with bones)',i,k)
      - ProdWeight('P_Breast1',i,k)
      - ProdWeight('P_Ham (boneless)',i,k)
      - ProdWeight('P_CutOff1',i,k)
       - ProdWeight('P_CutOff2',i,k)
      - ProdWeight('P_CutOff5',i,k)
      - ProdWeight('P_Sundry1',i,k)
      - ProdWeight('P_Sundry2',i,k)
      - ProdWeight('P_Sundry5',i,k)
      - ProdWeight('P_Tenderloin',i,k)  ;

Parameter BackDeduction(j,i,k) Decuction in price per kg at product weight in
excess of 3.5 kg per back (7 kg per pig) ;

BackDeduction('P_Backs (with bones)',i,k) = 2$(ProdWeight('P_Backs (with
bones)',i,k) gt 7) + 0$(ProdWeight('P_Backs (with bones)',i,k) le 7) ;

BackDeduction('P_Backs (boneless)',i,k) = 2$(ProdWeight('P_Backs
(boneless)',i,k) gt 7) + 0$(ProdWeight('P_Backs (boneless)',i,k) le 7) ;



Variables
    z      total profit

                ;

Binary Variables
    x(i,j,k) 1 if product j to be produced from pig i at weight increase k else
    0 ;
```

```
Equations
    profit     objective function
    back_con    maximum weight of back
    ham_con     ham maximum layer of fat 14 mm
    x1_con      constraint regarding fore-end
    x2_con      constraint regarding fore-end
    x3_con      constraint regarding fore-end
    x4_con      constraint regarding backs (middle piece) alternative 1
    x5_con      constraint regarding backs (middle piece) alternative 1
    x6_con      constraint regarding backs (middle piece) alternative 1
    x7_con      constraint regarding backs (middle piece) alternative 2
    x8_con      constraint regarding backs (middle piece) alternative 2
    x9_con      constraint regarding backs (middle piece) alternative 2
    x10_con     constraint regarding ham alternative 3
    x11_con     constraint regarding ham alternative 4
    x12_con     constraint regarding ham alternative 4
    x13_con     constraint re. always production of one tenderloin
    x14_con     constraint re. always production of one head
    x20_con     one back product only
    x21_con     one ham product only
    X22_con     newer production of help product H_8201
                                                 ;


profit ..        z  =e=   sum((i,j,k), (Price(j)-KamFradrag(j,i,k)
                       + PriceCoeff(j)*(FatLayer(i,k)-15.9))
                       * ProdWeight(j,i,k)* x(i,j,k)  );

back_con(k,i) ..           x(i,'P_Breast2',k)*ProdWeight('P_Breast2',i,k) =l= 8 ;
    ham_con(k,i) ..        x(i,'P_Ham',k)*FatLayer(i,k) =l= 14 ;
    x1_con(k,i) ..         x(i,'P_Schoulder',k) =e= x(i,'P_Neck',k) ;
    x2_con(k,i) ..         x(i,'P_Neck',k) =e= x(i,'P_CutOff1',k) ;
    x3_con(k,i) ..         x(i,'P_CutOff1',k) =e= x(i,'P_Sundry1',k) ;
    x4_con(k,i) ..         x(i,'P_Backs (with bones)',k) =e= x(i,'P_Breast1',k) ;
    x5_con(k,i) ..         x(i,'P_Breast1',k) =e= x(i,'P_CutOff2',k) ;
    x6_con(k,i) ..         x(i,'P_CutOff2',k) =e= x(i,'P_Sundry2',k) ;
    x7_con(k,i) ..         x(i,'P_Backs (boneless)',k) =e= x(i,'P_Breast2',k) ;
    x8_con(k,i) ..         x(i,'P_Breast2',k) =e= x(i,'P_CutOff3',k) ;
    x9_con(k,i) ..         x(i,'P_CutOff3',k) =e= x(i,'P_Sundry3',k) ;
    x10_con(k,i) ..        x(i,'P_Ham',k) =e= x(i,'P_Sundry4',k) ;
    x11_con(k,i) ..        x(i,'P_Ham (boneless)',k) =e= x(i,'P_CutOff5',k) ;
    x12_con(k,i) ..        x(i,'P_CutOff5',k) =e= x(i,'P_Sundry5',k) ;
    x13_con(k,i) ..        x(i,'P_Tenderloin',k) =e= 1 ;
    x14_con(k,i) ..        x(i,'P_Head',k) =e= 1 ;
    x20_con(k,i) ..        x(i,'P_Backs (with bones)',k) + x(i,'P_Backs
                           boneless)',k) =e= 1 ;
    x21_con(k,i) ..        x(i,'P_Ham',k) + x(i,'P_Ham (boneless)',k) =e= 1 ;
    x22_con(k,i) ..        x(i,'H_8201',k) =e= 0 ;


Model vaegt3d /all/ ;
Solve vaegt3d using mip maximizing z ;
```

```
Parameter Res(k) profit calculation at different weight scenarios ;
   Res(k) =  sum((i,j), (Price(j)-KamFradrag(j,i,k)
          + PriceCoeff(j)*(FatLayer(i,k)-15.9))*ProdWeight(j,i,k) * x.l(i,j,k));

Parameter Resimp(k) increasement in profit by increasing weight ;
   Resimp(k) = Res(k) - Res('w_0') ;

Parameter SlaughteringWeight(k)  SlaughteringWeight in kg at weight scenario
   SlaughteringWeight(k) = sum((i), PigWeight(i,k)) ;

Parameter Production(k) Production in kg at weight scenario k ;
   Production(k) = sum((i,j), ProdWeight(j,i,k)*x.l(i,j,k)) ;

Parameter AvgPrice(k)   Average price at weight scenario k ;
   AvgPrice(k) = Res(k)/Production(k);

Parameter AvgPriceChange(k) Change in average price at different weight
increases ;
   AvgPriceChange(k) = AvgPrice(k) - AvgPrice('w_0') ;

Parameter ProductionProduct(s,k) Production volume of sold product s (subset of
j) at weight scenario k ;
   ProductionProduct(s,k) = sum((i), ProdWeight(s,i,k)*x.l(i,s,k)) ;

Parameter TurnoverProduct(j,k) Average price for product j at weight scenario k
;
   TurnoverProduct(j,k) = sum((i), (Price(j) +

PriceCoeff(j)*FatLayer(i,k))*ProdWeight(j,i,k)*x.l(i,j,k)) ;

Parameter NumberProducts(s,k) Number of sold product s(subset of j) at weight
scenario k ;
   NumberProducts(s,k) = sum((i), x.l(i,s,k)) ;


Display Res;
Display Resimp;
Display SlaughteringWeight;
Display Production;
Display AvgPrice;
Display AvgPriceChange;
Display ProductionProduct;
Display TurnoverProduct;
Display NumberProducts ;
```