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The Value of Improved Measurements in a Pig Slaughterhouse

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Abstract

The pig industry is an essential and 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 potential new competitors from low cost countries can be expected to enter the traditional Danish export markets. Therefore it is more important than ever to optimize all aspects of Danish pig production, slaughtering processes and delivery. This paper concerns the aspects of optimization at the slaughterhouses regarding estimation of the value of improved measurements.

The slaughterhouse industry differs from the traditional industry in a number of ways. There is a large natural variation in the raw materials regarding quality, weight, size, lean meat percentage, as a consequence of pigs being a biological material. The slaughterhouses handle this large variation by sorting the pigs into groups consisting of pigs with almost the same characteristics and thereby reducing the variation within the individual sorting groups substantially. The accuracy of the measurements is the most important limiting factor for how much the variation within each sorting group can actually be reduced. Substantial investments are expected to improve the quality of the measurements further. This paper concerns the use of Operations Research to solve a practical problem, which is of major importance for the industry, namely to improve the estimation of the economic effects of improved measurements. The benefit for the industry is obviously to be able to decide upon the level of measuring accuracy worth investing in.

The main conclusion is that even relatively simple optimization models can advantageously be used to improve the basis of the slaughterhouses for making decisions regarding improved measurements. The model is a Mixed Integer Programming (MIP) model and is used to compute the consequences of improved measurements and analyze different scenarios regarding restrictions in sales volume and quality restrictions.

The assumptions regarding pricing and cost are found to be very important to obtain a true and fair view of the size of the profit. For future (and improved) computations the net prices used can advantageously be split into 3-4 different contributions, which should be estimated separately for each product.

1 Background

The pig industry is essential for Danish economy and in 2006 more than 25 million pigs were produced in Denmark and approx. 90% of the meat was exported. The export value amounted to DKK 28.8 billion [Danish Meat Association (2007)].

Competition in the pork industry is substantial and the feeding costs have increased considerably. Therefore it is increasingly important that Danish farmers and slaughterhouses continuously optimize their production. This paper concerns the aspects of optimization at the slaughterhouses.

Even within our neighbouring countries the competition is hard and pressure is on the slaughterhouses to offer the best payments to the farmers. During the last couple of years, a substantial number of Danish farmers have started delivering part of their pigs to German slaughterhouses.

The slaughterhouse industry differs from the traditional industry in a number of ways: Pigs and meat are biological materials with a high degree of natural variation in quality, weight, size, meat content (lean meat percentage) etc. The way slaughterhouses handle this variation is by sorting the pigs into different sorting groups in which pigs with almost the same characteristics are placed. The sorting can be based on a number of factors, each describing some quality characteristics. However, one problem is that the measurement of those characteristics is not trivial at all nor is the current accuracy overwhelming:

- The measurements often have quite an indirect nature. For instance, today the lean meat percentage is estimated based on a number of ultrasound measurements at different parts of the pig. Those measurements are mathematically transformed into a value, which is an estimation of the lean meat percentage. Due to variability in size and shapes as well as to the fixation of pigs during the measurements many noise factors interfere. The differences in the exact fixation might result in measurements being performed in slightly different places of the pigs.

- There is only a limited time to perform the measurements, as the throughput of a slaughtering line is approx. 350 pigs per hour.

New and improved technology makes it possible to obtain better and more accurate measurements of the pigs. Using CT scanners instead of ultrasound for instance makes it possible to measure the lean meat percentage almost without noise and very close to the true/correct values. Today, these true values can only be found in relatively small experiments, by costly dissections of the pigs.

2 Literature survey

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 Measurements

As mentioned before, the accuracy of the measurements is very important for how precise the pigs are placed in the respective sorting groups and thereby essential for how well the pigs fit the production chosen. This directly influences the net prices obtainable and the profit for the pigs being produced.

Even though Danish slaughterhouses on an international scale are in the forefront regarding classification and measuring of the quality of the pigs, the measuring is - as described - characterized by substantial uncertainties. With the current measuring accuracy it is unavoidable that some pigs are placed into wrong sorting groups. Consequently, some pigs are used for products, for which they are not well suited resulting in additional costs, lower obtainable prices and unsatisfied customers.

As an extreme, one could imagine the effect of having online CT scanners at the slaughtering lines. Depending on how fine the scanning is performed and whether all parts of the pigs are being scanned, measurements with an almost 100% accuracy can be obtained. Another important way to improve the measuring accuracy is to improve the physical fixing of the pigs to ensure that the measurements are performed at the exact intended place of the pig.

The measuring system's ability to measure accurately is specified by its standard error of prediction (SEP). The standard error of prediction is found as the standard deviation of the differences between the measured values and the reference values (true values) using a test data set.

Some of the key issues in connection with measuring accuracy are shown in the following example, where the relations between the measured and true qualities (here determined by the fat layer in millimetres) are shown:

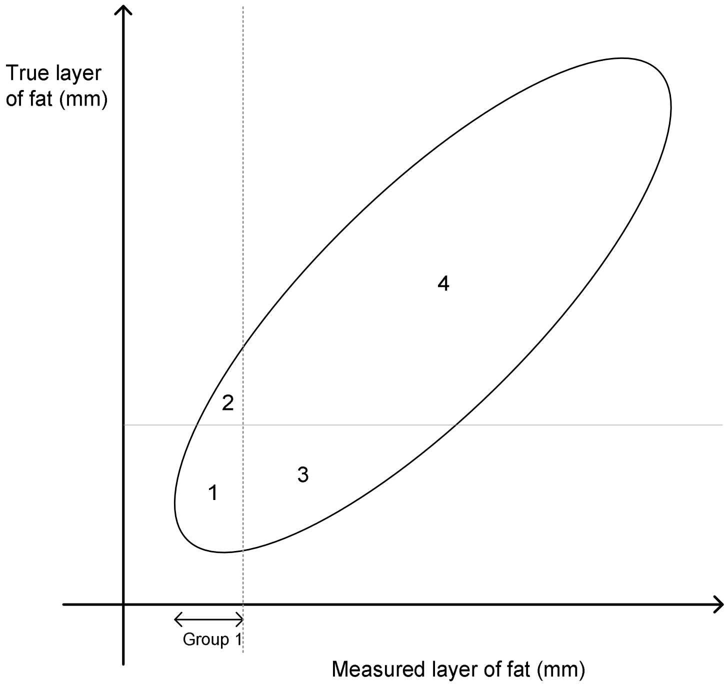

Figure 1. Relations between measured and true values of the fat layer.

The example regards backs sorted into four different sorting groups based on the measured fat layer.

In this example the four sorting groups are identified as follows[1]:

Sorting group 1	the 10% leanest backs (as measured)
Sorting group 2	the following 30% leanest backs (as measured)
Sorting group 3	the next 15% leanest backs (as measured)
Sorting group 4	the remaining 45% of the backs (as measured)

Sorting group 1 consists of the 10 % leanest backs (as measured) and will be used for products, where lean qualities are preferred. In Figure 1 above, sorting group 1 is found in the areas marked 1 and 2. Area 1 consists of the products of the highest quality, which fully lives up to specifications and are sorted correctly. Products in area 2 do not fully live up to specifications for raw materials to be used for those products. It will immediate be profitable for the slaughterhouses to have some products in area 2 as long as the level is considered acceptable (maybe 5-15%) for the customers. The large degree of variation in meat has made customers within the industry familiar to this kind of

[1] Only for illustrative purposes in this paper. The groups do not in any way reflect the sorting practice in Danish Crown or Tican.

problems and they accept a small part of the deliverances not living up to specifications. However, the strategic value of being able to deliver precise the quality promised, is considered to be very considerable.

The area marked 3 consists of products, which have been classified as not being part of sorting group 1 by mistake. This is probably the most costly of the four areas as the raw materials are used for products, which are sold too cheap compared to their true quality. The products in area 4 are the products, which have been correctly sorted off.

An improvement in measurements will make the ellipse “slimmer” as shown in Figure 2 below. The number of pigs not sorted correctly decreases significantly (area 2 and 3). Especially notable is the limited number of pigs within sorting group 1 not living up to specifications (area 2). Similar considerations can be made for sorting groups 2, 3 and 4.

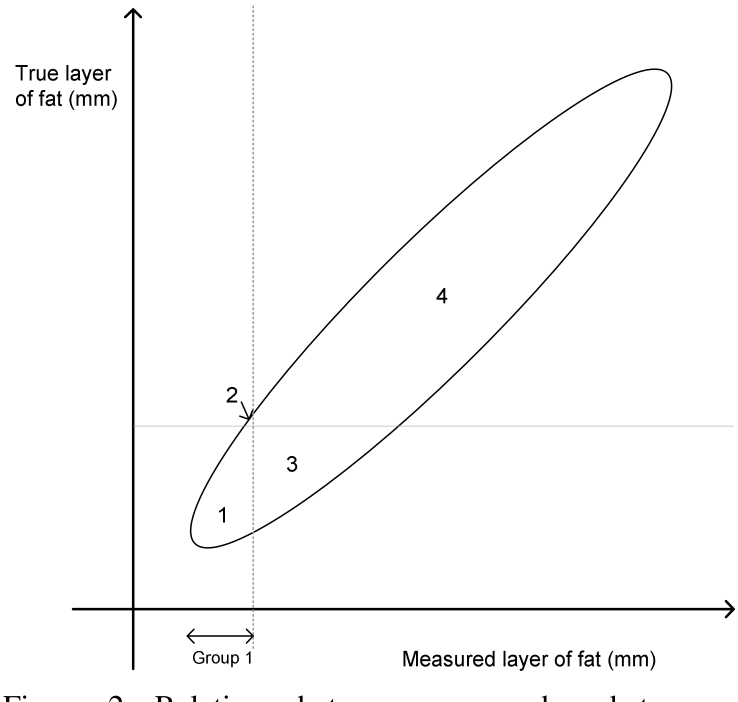

Figure 2. Relations between measured and true values of the fat layer when measurements are improved

Alternatively, sorting group 1 can be widened to include pigs with a larger measured fat layer. In figure 2, this corresponds to a displacement of the vertical line to the right on the x-axis. By so doing more of the pigs will be placed in the leaner sorting groups without increasing the level of pigs not living up to specifications compared to the current situation.

4 The Model

The purpose of the model is to investigate the economic benefits of improved measuring accuracy. The model was the first model developed and is a relative simple model only using one product type at a time and was used to obtain knowledge of short comings and other requirements for future models. The measuring noise has been simulated at the current level of the standard error of prediction (SEP) and at an improved level where SEP has been halved. Benefits are then found by performing two optimizations with data at these two levels of measuring accuracy. The improvement can be found as the difference in profits of these two optimizations.

We have a set of backs from carcasses which are placed into different sorting groups $\mathcal{I}=\{1,\dots,I\}$ based on their measured quality. Each carcass can be used to produce a set of different back product $\mathcal{J}=\{1,\dots,J\}$. The decision variable $x_{i,j}$ indicate the number of pigs from sorting group i used to produce product j. The variable $y_{i,j}$ is a binary variable with the value 1 if sorting group i is used to produce product j and 0 otherwise and is used to control the number of products made of a quality without of specifications. The problem is to find the optimal utilization of each sorting group and the total profit for the optimal solution given the carcasses' distribution on sorting groups (Distribution_i) and restrictions in the maximum sale of each product (MaxSale_j). Furthermore, there are restrictions that the number of products not living up to the quality specifications (QualityLow_j) cannot exceed the acceptable level (AcceptableQuality).

4.1 Mathematical formulation of the model

The objective function:

1) $$Max.\, Z = \sum_{i,j} \Pr ice_{i,j} \cdot x_{i,j} \cdot AverageWeight$$

Subject to:

2) $$\sum_{j} x_{i,j} \leq Distribution_i \qquad \forall\ i \in \mathcal{I}$$

3) $$\sum_{i} x_{i,j} \big/ (N \cdot 100) \leq MaxSale_j \qquad \forall\ j \in \mathcal{J}$$

4) $$y_{i,j} \leq x_{i,j} \qquad \forall\ i \in \mathcal{I},\ j \in \mathcal{J}$$

5) $$y_{i,j} \bullet M \geq x_{i,j} \qquad \forall\ i \in \mathcal{I},\ j \in \mathcal{J}$$

6) $SumQualityLow_j = \sum_i QualityLow_{i,j} \cdot y_{i,j} \qquad \forall \ j \in \mathcal{J}$

7) $SumQualityLow_j \leq AcceptableQuality \cdot \sum_i x_{i,j} \qquad \forall \ j \in \mathcal{J}$

8) $x_{i,j} \geq 0 \qquad \forall \ i \in \mathcal{I}, \ j \in \mathcal{J}$

9) $y_{i,j} = \begin{Bmatrix} if \ \ production: 1 \\ else: \qquad 0 \end{Bmatrix} \quad \vdots \qquad \forall \ i \in \mathcal{I}, \ j \in \mathcal{J}$

Indices:
i: sorting group i based on the measured meat quality.
j: product j.

Variables:
$x_{i,j}$: Number of pigs from sorting group i used to produce product j.
$y_{i,j}$: 1 if carcass i is used to produce product j; else 0.

Parameters:

$Distribution_i$:	Number of pigs available in sorting group i.
$MaxSale_j$:	Maximum sale of products j in percentage of the total number of pigs.
$QualityLow_{i,j}$:	Numbers of pigs from sorting group i not living up to the desired specifications for product j.
$Price_{i,j}$:	Net price for product j if raw materials come from sorting group i.
$QualityLow_{i,j}$:	Number of items in sorting group i not living up to specifications for producing product j.
$SumQualityLow_j$:	Sum of items not living up to specifications for producing product j.
AcceptableQuality:	Acceptable level (percentage) for items not living up to specifications for producing the products. The acceptable level is valid for each product.
AverageWeight:	Average weight of back.
N:	Number of pigs in the sample.

4.2 Description of the Model:

The model has been set up using 5 different back products, but can easily be modified to include more products and also to cover the remaining parts of the pig, e.g. the fore-end and the ham.

In the experiments we use approximately 60 different sorting groups (quality groups) based on the measured quality values. Actual slaughtering data from approx. 61,000 pigs slaughtered in one of the Danish slaughterhouses are used as input for the model. Data has been collected during May/June 2005. The data has been used to estimate the distribution of pigs on different sorting groups as well as the percentage of pigs placed in each group not living up to specifications for producing different products.

The pigs are placed into different sorting groups depending on the estimated "measured values" of the quality. The placement into sorting groups is therefore depending on the level of measuring accuracy. Estimation of the model parameters is commented on in detail in the section Estimation of Model Parameters.

4.2.1 Pricing

In general, the five different products in question can all be produced from different sorting groups. Some sorting groups, however, are more suitable for some products than others, according to the need for trimming of the products to a certain fat layer or length. A high suitability results in less work when products are further processed and in a larger yield (the weight of the main product, where the best prices can be obtained, as a percentage of the total weight of the part).

The most suitable thickness of the fat layer for different products is given in Table 1 below:

	Product 1	Product 2	Product 3	Products 4	Product 5
Most suitable layer of fat (thickness - mm)	0-9	0-11	0-15	0-18	all

Table 1. Most suitable layer of fat for the different products

When a product is made from pigs outside the intervals above it is designated to be outside the specifications.

In order to take the suitability into consideration an additional cost is added to the products made from raw materials outside the specifications. This results in the prices shown in Appendix 1 based on the true value of the fat layer. These prices are then transformed into prices obtainable for different sorting groups and are calculated individually for each level of measuring accuracy.

The prices are transformed from being based on the true fat layer to be based on sorting groups. This is done by finding the average price per kg for each of the five products for the carcasses in each sorting group. By so doing, it is indirectly assumed, that for the individual product a price can be obtained that reflects its true fat layer no matter from which sorting group it comes. See the chapter "Discussion" for further information regarding the importance of assumptions in prices.

4.2.2 Quality

As long as there is measuring noise it is unavoidable that some pigs are placed into wrong sorting groups and that products are being produced from pigs which were not intended for these products.

The number of pigs placed into sorting groups not living up to specifications for producing different products is estimated through simulation. The model keeps track of the number of items not living up to specifications for different optimized solutions. Estimation of the model parameters is commented on in detail in the section Estimation of Model Parameters.

4.2.3 Max sale

The maximum allowed sale is established for each product as a percentage of the total number of items (here approx. 61,000), which can be used to produce the products in question. As default the maximum sale for each product is set to 100% i.e. there are no restrictions in the sales volumes for any of the products.

4.3 Estimation of Model Parameters:

4.3.1 Estimation of the measured values of the fat layer

The estimation is based on registered slaughtering data for approx. 61.000 pigs. In order to work with different sizes of measuring accuracy, the registered quality values are considered as true values. The measured values of the quality have been estimated at two different levels of measuring noise by simulating some measuring noise for each pig and adding it to the registered quality values.

The two different levels of measuring noise chosen are the current level of the standard error of prediction (SEP) and an improved level in which SEP has been halved.

4.3.2 Estimation of prices

The estimation of prices is based on net prices from Appendix 1, given for the true fat layer after reductions for additional costs if the raw materials are not considered most suitable for the specific products.

5 Results

The economic consequences of improved measurements are found by performing two optimizations: One with data from the improved accuracy and one with the current measuring accuracy. The improvement can be found as the difference in profits between these two optimizations. The computations in this paper are for illustrative purposes and as prices vary over time a price and cost study should be performed before the computations are used for actual decision support.

The following three different scenarios are investigated:

1. No constraints in volume and quality
2. Constraints in volume
3. Constraints in quality

5.1 Results without constraints in volume and quality

In the first scenario there are no constraints in sales volume nor in quality. The individual sorting groups will be used to produce the product for which the highest net price can be obtained, given the distribution of the true fat layer.

Improved measuring accuracy increases the profit by DKK 75,296 for the approximately 61,000 pigs, being part of the experiment, equalling an increase in profits by 0.83% for the products. For Danish slaughterhouses, which produce approx. 25 million pigs annually, it would amount to DKK 31 million per year.

Measuring accuracy	Profit
SEP 20.00	9,181,962
SEP 41.28	9,106,666
Improved profit	75,296

Table 2. Improved profit due to improved measurements

5.2 Results with constraints in sales volume

To make the estimations more realistic constraints have been added regarding the maximum sales for different products. Three different alternatives for the maximum sales of different products are used:

	Product 1	Product 2	Product 3	Product 4	Product 5
Scenario 1	25%	25%	25%	25%	100%
Scenario 2	20%	20%	20%	20%	100%
Scenario 3	10%	15%	25%	25%	100%

In all three alternatives it is assumed that there are no restrictions regarding the sale of Product 5.

Measuring accuracy	Profit - sub scenario 1	Profit - sub scenario 2	Profit - sub scenario 3
SEP 20.00	9,101,347	9,046,513	9,055,337
SEP 41.28	9,019,039	8,962,523	8,990,778
Improved profit	82,308	83,990	64,559

Table 3. Improved profit due to improved measurements with constraints in sales

Introducing constraints in the sales volumes decreases the level of profit, but improved measurements still results in an increased profit of between DKK 64,559 and DKK 83,990 for the three scenarios for the approx. 61,000 pigs. This is an increase in profits between 0.72% and 0.94%, and for the Danish slaughterhouses it amounts to between DKK 26 and DKK 31 million annually.

The share of products produced from raw materials not living up to specifications decreases substantially with the improved measurements and is reduced by 33%, 25% and 57% respectively for sub scenario 1, 2 and 3. The two leanest products (product 1 and 2) are, however, still at a relatively high level. For the three sub scenarios, 15% - 23% of the raw materials used to produce product 1 are not living up to specifications. For product 2, the same share of raw materials is between 7% - 22%.

5.3 Results with constraints in quality

In the third scenario, constraints regarding the percentage of items not living up to specifications are introduced. Three different levels of the percentage allowed not being within specifications, namely 15%, 10% and 5%, are investigated. It is noticed, that product 5 can be produced of all qualities, but the net prices obtainable are heavily influenced by the fat layer.

Measuring accuracy	Profit - max 15% not within spec.	Profit - max 10% not within spec.	Profit - max 5% not within spec.
SEP 20.00	9,181,962	9,181,962	9,171,382
SEP 41.28	9,106,666	9,103,292	9,085,276
Improved profit	75,296	78,670	86,106

Table 4. Improved profit due to improved measurements with constraints re. quality

There will be no cost of introducing a constraint that allows a maximum of 15% of a product to be produced of raw materials not within specifications, as an optimal production even without limitations would only have a share of maximum 14% for one of the products. Improved measurements would result in an increase in profits by DKK 75,296.

Strengthening the constraints decreases the level of profit, but improved measurements still results in an increased profit of DKK 78,296 and DKK 86,106 for constraints allowing a maximum of 10% and 5% respectively to be outside specifications. This equals an improvement of 0.82% - 0.94% for the three levels investigated.

For the Danish slaughterhouses improved measurements would result in an increase in the profits by DKK 31-35 millions annually for the back products under the different quality scenarios.

The GAMS code used for the modelling can be seen in Appendix 2. The model has 731,938 constraints and 595 variables and was solved to optimality in less than 0.2 seconds, which can be considered very acceptable.

6 Discussion

The assumption chosen regarding pricing and cost is of key importance for obtaining a true and fair view of the size of the profit and thereby to calculate the economic consequences of improved measurements. By using the net prices as in this paper, it is indirectly assumed that for the individual raw materials a net price, which reflect its true fat layer, can be obtained.

This assumption correctly takes into account that a product produced of raw materials outside specifications may have extra costs for trimming and waste. For products made of raw materials, which are better (leaner) than required for the given product the assumption is less than perfect. The customers would hardly pay a premium for receiving products, which are better than the ones they had actually ordered.

As correct net prices are so essential for obtaining reliable results, the prices can advantageously be split into the price itself and three different cost contributions:

Cost contribution 1 (cost of using raw material of too good a quality):

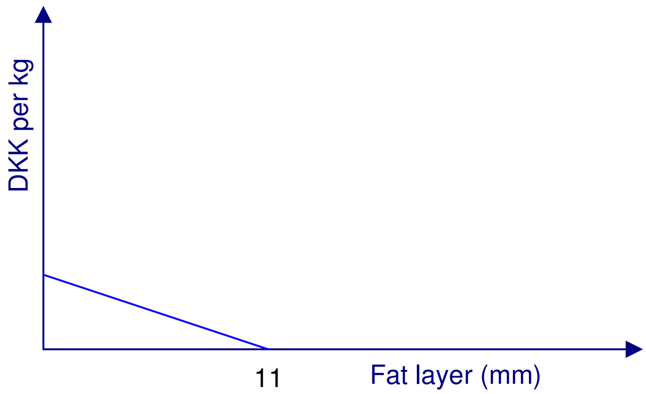

Figure 3. Cost of using raw material of too good a quality

Figure 3 above shows the cost of delivering products produced of a better quality than required. This is a marginal cost consideration, where profit lost by not receiving the highest price for raw materials is considered a cost.

Cost contribution 2 (additional cost for extra trimming and waste due to raw materials not living up to specifications):

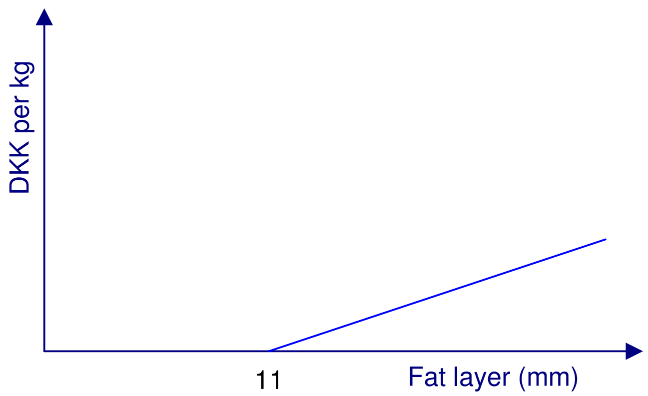

Figure 4. Additional cost for extra trimming and waste due to raw materials not living up to specifications.

Figure 4 shows the additional costs for extra trimming and waste (lower yield) as a consequence of raw materials being outside specifications. The contribution from figure 4 can be split into two separate contributions: 1) additional cost for extra trimming and 2) additional costs for waste. For many products the first contribution is almost the same no matter if the products are trimmed by 2 or 8 mm.

Cost/profit contribution 3 (Cost/profit for delivering products produced of raw materials not living up to specifications:

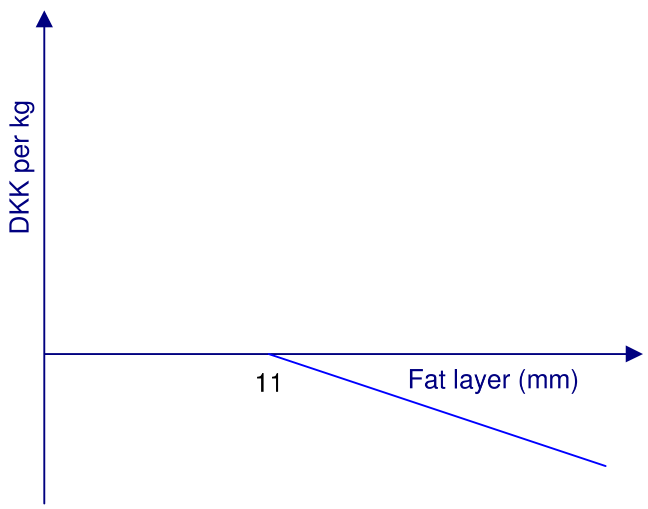

Figure 5. Cost/profit for delivering products produced of raw materials not living up to specifications.

Figure 5 shows the immediate profit of delivering products produced of raw materials being outside specifications. This, however, is only true as long as it is at an acceptable level and as long as the difference between actual quality and specifications is not too big. If the slaughterhouses could improve the measuring accuracy and deliver more homogenous products, the slaughterhouses might be able to obtain higher prices. This contribution is very hard to estimate, but it is believed to be considerably larger than the profit contribution from Figure 5. Central persons within the industry are convinced that the value is of a very considerable size, may be even as big as the computed profit of improved measurements. A study must be made tracing added value in the complete process from slaughterhouse to end user. Case studies should be performed, involving marketing and sales personnel as well as product and process specialists from Danish slaughterhouses and the Danish Meat Association. Scenario analysis can be used to analyse how the value added may be split between the slaughterhouses and their customers. Such a study involves both the slaughterhouses and its customers, and further planning and research should be made before initiating the study.

The three cost/profit contributions, i.e.: 1) Cost of using raw material of too good a quality; 2) Additional cost for extra trimming and waste due to raw materials not living up to specifications; 3) Cost/profit for delivering products produced of raw materials not living up to specifications (see Figure 3, 4 and 5) should be estimated separately for each product. A study can be performed at the slaughterhouses establishing how different products are distributed on different qualities (quality groups) before delivery. CT scanners, manual quality control and statistical testing can be used to establish the quality. The additional costs for extra trimming and cutting can be estimated by completing time and yield studies at the cutting departments. The cost of delivering a better quality than required and the immediate profit of delivering a quality not living up to specifications can be estimated when the distribution on different qualities are known and a price study has been performed, involving marketing and sales personnel.

7 Conclusion

The main conclusion is that even relatively simple optimization models can advantageously be used to improve the basis of the slaughterhouses for making decisions regarding improved measurements. The value of improved measurements has been estimated using Mixed Integer Programming under three different scenarios where different limitations in volume and quality were introduced. The consequences of improved measurements on quality and profit were investigated.

Improved measurements make it possible for the slaughterhouses to produce more lean products without receiving complaints from customers. Furthermore, the percentage is reduced of products produced of a lower quality than desired. The improved sorting in the form of more correct placements into sorting groups results in a substantial improvement in profit. The same effect can be seen when constraints regarding volume and quality are introduced.

The assumptions chosen regarding pricing and costs are very important for obtaining a true and fair view of the profit. In order to make the prices reflect the actual cost even more realistically, the costs can advantageously be split into the following four different contributions:

- "Cost" of delivering a better quality than required. It is a marginal cost consideration, where "lost profit" by not obtaining the best price possible is considered a cost.

- Contribution from delivering products from raw materials outside specifications.

- Waste in connection with extra trimming as a consequence of raw materials being outside specifications. The waste both relates to the actual waste and the cut-off meat, which is sold at lower prices than the main product.

- Cost of extra cutting etc. as a consequence of raw materials being outside specifications. For many products, it is not necessary to take this contribution into account, as cutting costs will often be the same, no matter if the product is trimmed by 2 or 8 mm.

The different contributions should be estimated separately for each product.

In reality, the economic consequences of improved measurements would be considerably higher than calculated in this paper as the contribution from delivering a better quality than required is not taken into account, and the contribution from delivering a quality which is outside specifications is only partly considered. In order to take those effects into consideration new cost analysis should be performed at the Danish slaughterhouses estimating the above mentioned four cost contributions for each product.

Furthermore, improved measurement would provide a considerable strategic value as the slaughterhouses would be able exactly to (or at least closer to) deliver the quality, which the customers require. It is very difficult to quantify this strategic value, but the slaughterhouses are of the opinion that it is of a considerable size and maybe even more important than the calculations of the non strategic values.

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.

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.

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 – price per kg depending on quality (based on fat layer in mm)

	Products				
fat layer (mm)	Product 1	Product 2	Product 3	Product 4	Product 5
0,5	15,23	14,73	14,23	13,73	16,25
1,0	15,20	14,70	14,20	13,70	16,10
1,5	15,18	14,68	14,18	13,68	15,95
2,0	15,15	14,65	14,15	13,65	15,80
2,5	15,13	14,63	14,13	13,63	15,65
3,0	15,10	14,60	14,10	13,60	15,50
3,5	15,08	14,58	14,08	13,58	15,35
4,0	15,05	14,55	14,05	13,55	15,20
4,5	15,03	14,53	14,03	13,53	15,05
5,0	15,00	14,50	14,00	13,50	14,90
5,5	14,98	14,48	13,98	13,48	14,75
6,0	14,95	14,45	13,95	13,45	14,60
6,5	14,93	14,43	13,93	13,43	14,45
7,0	14,90	14,40	13,90	13,40	14,30
7,5	14,88	14,38	13,88	13,38	14,15
8,0	14,85	14,35	13,85	13,35	14,00
8,5	14,83	14,33	13,83	13,33	13,85
9,0	14,80	14,30	13,80	13,30	13,70
9,5	*12,78*	14,28	13,78	13,28	13,55
10,0	*12,75*	14,25	13,75	13,25	13,40
10,5	*12,73*	14,23	13,73	13,23	13,25
11,0	*12,70*	14,20	13,70	13,20	13,10
11,5	*12,68*	*12,18*	13,68	13,18	12,95
12,0	*12,65*	*12,15*	13,65	13,15	12,80
12,5	*12,63*	*12,13*	13,63	13,13	12,65
13,0	*12,60*	*12,10*	13,60	13,10	12,50
13,5	*12,58*	*12,08*	13,58	13,08	12,35
14,0	*12,55*	*12,05*	13,55	13,05	12,20
14,5	*12,53*	*12,03*	13,53	13,03	12,05
15,0	*12,50*	*12,00*	13,50	13,00	11,90
15,5	*12,48*	*11,98*	*11,48*	12,98	11,75
16,0	*12,45*	*11,95*	*11,45*	12,95	11,60
16,5	*12,43*	*11,93*	*11,43*	12,93	11,45
17,0	*12,40*	*11,90*	*11,40*	12,90	11,30
17,5	*12,38*	*11,88*	*11,38*	12,88	11,15
18,0	*12,35*	*11,85*	*11,35*	12,85	11,00
18,5	*12,33*	*11,83*	*11,33*	*10,83*	10,85
19,0	*12,30*	*11,80*	*11,30*	*10,80*	10,70
19,5	*12,28*	*11,78*	*11,28*	*10,78*	10,55
20,0	*12,25*	*11,75*	*11,25*	*10,75*	10,40
20,5	*12,23*	*11,73*	*11,23*	*10,73*	10,25
21,0	*12,20*	*11,70*	*11,20*	*10,70*	10,10
21,5	*12,18*	*11,68*	*11,18*	*10,68*	9,95
22,0	*12,15*	*11,65*	*11,15*	*10,65*	9,80
22,5	*12,13*	*11,63*	*11,13*	*10,63*	9,65
23,0	*12,10*	*11,60*	*11,10*	*10,60*	9,50
23,5	*12,08*	*11,58*	*11,08*	*10,58*	9,35
24,0	*12,05*	*11,55*	*11,05*	*10,55*	9,20
24,5	*12,03*	*11,53*	*11,03*	*10,53*	9,05
25,0	*12,00*	*11,50*	*11,00*	*10,50*	8,90
25,5	*11,98*	*11,48*	*10,98*	*10,48*	8,75
26,0	*11,95*	*11,45*	*10,95*	*10,45*	8,60
26,5	*11,93*	*11,43*	*10,93*	*10,43*	8,45
27,0	*11,90*	*11,40*	*10,90*	*10,40*	8,30

Apppendix 2 – 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       kval2 værdi     /  k30,  k40,  k50,  k60,  k70,  k80,  k90,
             k100, k110, k120, k130, k140, k150, k160, k170, k180, k190,
             k200, k210, k220, k230, k240, k250, k260, k270, k280, k290,
             k300, k310, k320, k330, k340, k350, k360, k370, k380, k390,
             k400, k410, k420, k430, k440, k450, k460, k470, k480, k490,
             k500, k510, k520, k530, k540, k550, k560, k570, k580, k590,
             k610, k630 /
     j       produkter      /  Product1, Product2, Product3, Product4, Product5 / ;


 PARAMETER
     Fordeling(i) Number of carcasses available in sorting group i
         /
               k30            2
               k40           11
               k50           23
               k60           87
               k70          135
               k80          274
               k90          486
               k100         687
               k110         995
               k120        1286
               k130        1681
               k140        2113
               k150        2319
               k160        2592
               k170        2845
               k180        3114
               k190        3294
               k200        3392
               k210        3410
               k220        3394
               k230        3293
               k240        3188
               k250        2946
               k260        2673
               k270        2455
               k280        2166
               k290        1962
               k300        1736
               k310        1447
               k320        1209
               k330        1052
               k340         857
               k350         745
               k360         580
               k370         480
               k380         379
```

k390	362
k400	283
k410	244
k420	160
k430	108
k440	112
k450	101
k460	73
k470	54
k480	44
k490	35
k500	23
k510	22
k520	14
k530	18
k540	13
k550	5
k560	7
k570	4
k580	1
k590	1
k610	1
k630	1 /

Afsaet_max(j) Max sale of product j (in percentage)

/	Product1	100
	Product2	100
	Product3	100
	Product4	100
	Product5	100 / ;

Table Kvalitet(i,j) Number of items in sorting group i not living up to specification when producing product j

	Product1	Product2	Product3	Product4	Product5
k30	0	0	0	0	0
k40	0	0	0	0	0
k50	0	0	0	0	0
k60	0	0	0	0	0
k70	0	0	0	0	0
k80	1	0	0	0	0
k90	4	0	0	0	0
k100	11	1	0	0	0
k110	51	0	0	0	0
k120	148	0	0	0	0
k130	324	2	0	0	0
k140	653	10	0	0	0
k150	1080	23	0	0	0
k160	1597	66	0	0	0
k170	2188	161	0	0	0
k180	2694	366	0	0	0
k190	3088	745	0	0	0
k200	3294	1181	0	0	0
k210	3374	1766	0	0	0
k220	3386	2244	0	0	0
k230	3289	2633	0	0	0
k240	3188	2847	0	0	0
k250	2946	2798	5	0	0
k260	2673	2615	10	0	0
k270	2455	2429	47	0	0
k280	2166	2162	81	0	0
k290	1962	1961	175	0	0
k300	1736	1736	273	0	0
k310	1447	1447	409	0	0
k320	1209	1208	531	0	0

k330	1052	1052	617	0	0
k340	857	857	650	0	0
k350	745	745	624	5	0
k360	580	580	545	19	0
k370	480	480	470	36	0
k380	379	379	377	39	0
k390	362	362	361	98	0
k400	283	283	283	114	0
k410	244	244	244	141	0
k420	160	160	160	110	0
k430	108	108	108	83	0
k440	112	112	112	103	0
k450	101	101	101	93	0
k460	73	73	73	72	0
k470	54	54	54	54	0
k480	44	44	44	44	0
k490	35	35	35	35	0
k500	23	23	23	23	0
k510	22	22	22	22	0
k520	14	14	14	14	0
k530	18	18	18	18	0
k540	13	13	13	13	0
k550	5	5	5	5	0
k560	7	7	7	7	0
k570	4	4	4	4	0
k580	1	1	1	1	0
k590	1	1	1	1	0
k610	1	1	1	1	0
k630	1	1	1	1	0 ;

Table Pris(i,j) Price for sorting group i for product j

	Product1	Product2	Product3	Product4	Product5
k30	14.9125	14.4125	13.9125	13.4125	14.3750
k40	14.9227	14.4227	13.9227	13.4227	14.4364
k50	14.9293	14.4293	13.9293	13.4293	14.4761
k60	14.9221	14.4221	13.9221	13.4221	14.4328
k70	14.9113	14.4113	13.9113	13.4113	14.3678
k80	14.8947	14.4020	13.9020	13.4020	14.3120
k90	14.8707	14.3871	13.8871	13.3871	14.2228
k100	14.8418	14.3727	13.8763	13.3763	14.1581
k110	14.7522	14.3563	13.8563	13.3563	14.0378
k120	14.6072	14.3434	13.8434	13.3434	13.9606
k130	14.4246	14.3232	13.8253	13.3253	13.8517
k140	14.1629	14.3005	13.8087	13.3087	13.7522
k150	13.8098	14.2744	13.7916	13.2916	13.6497
k160	13.4543	14.2301	13.7746	13.2746	13.5477
k170	13.0747	14.1559	13.7556	13.2556	13.4337
k180	12.8025	14.0301	13.7386	13.2386	13.3319
k190	12.5653	13.8147	13.7211	13.2211	13.2266
k200	12.4099	13.5747	13.7053	13.2053	13.1319
k210	12.2570	13.2288	13.6854	13.1854	13.0126
k220	12.1452	12.9267	13.6693	13.1693	12.9157
k230	12.0380	12.6168	13.6518	13.1518	12.8108
k240	11.9282	12.3683	13.6339	13.1339	12.7032
k250	11.8286	12.1823	13.6134	13.1173	12.6036
k260	11.7210	12.0296	13.5909	13.0993	12.4960
k270	11.6177	11.9096	13.5390	13.0821	12.3927
k280	11.5145	11.7923	13.4799	13.0649	12.2895
k290	11.4101	11.6859	13.3441	13.0475	12.1851
k300	11.3036	11.5786	13.1704	13.0298	12.0786
k310	11.2002	11.4752	12.8606	13.0125	11.9752
k320	11.0986	11.3749	12.4719	12.9956	11.8736
k330	10.9978	11.2728	12.0964	12.9788	11.7728
k340	10.8726	11.1476	11.6337	12.9579	11.6476
k350	10.7735	11.0485	11.3788	12.9248	11.5485

```
k360      10.6517   10.9267   11.0517   12.8388   11.4267
k370      10.5438   10.8188   10.8617   12.7139   11.3188
k380      10.4415   10.7165   10.7276   12.6268   11.2165
k390      10.3112   10.5862   10.5920   12.1691   11.0862
k400      10.2250   10.5000   10.5000   11.8071   11.0000
k410      10.1217   10.3967   10.3967   11.3355   10.8967
k420      10.0328   10.3078   10.3078   11.0156   10.8078
k430       9.9236   10.1986   10.1986   10.7310   10.6986
k440       9.8232   10.0982   10.0982   10.2759   10.5982
k450       9.6963    9.9713    9.9713   10.1537   10.4713
k460       9.5736    9.8486    9.8486    9.8808   10.3486
k470       9.4528    9.7278    9.7278    9.7278   10.2278
k480       9.3250    9.6000    9.6000    9.6000   10.1000
k490       9.3079    9.5829    9.5829    9.5829   10.0829
k500       9.0446    9.3196    9.3196    9.3196    9.8196
k510       8.9500    9.2250    9.2250    9.2250    9.7250
k520       8.9179    9.1929    9.1929    9.1929    9.6929
k530       8.7750    9.0500    9.0500    9.0500    9.5500
k540       8.7712    9.0462    9.0462    9.0462    9.5462
k550       8.6350    8.9100    8.9100    8.9100    9.4100
k560       8.6179    8.8929    8.8929    8.8929    9.3929
k570       8.3875    8.6625    8.6625    8.6625    9.1625
k580       8.1250    8.4000    8.4000    8.4000    8.9000
k590       8.2750    8.5500    8.5500    8.5500    9.0500
k610       8.1250    8.4000    8.4000    8.4000    8.9000
k630       8.1250    8.4000    8.4000    8.4000    8.9000  ;

Variables
    x(i,j) number of pigs from sorting group i used for product j
    z     total profit
    kval_ringe_sum(j)
    prod_sum(j)  ;

 Binary Variables
    y(i,j) 1 if product j is produced from sorting group i, else 0 ;

 Positive Variable x ;


 Equations
      profit                  objective function
      distribution_con        constraint re. number of pigs available in sorting group
      sale_con                constraint re. max sale
      y1_con                  constraint re. production
      y2_con                  constraint re. production
      production_sum          sum of production
      quality_con             constraint re. quality ;


      profit ..      z  =e=       sum((i,j), Pris(i,j) * x(i,j)*11);
      distribution_con(i) ..      sum(j, x(i,j)) =l= Fordeling(i);
      sale_con(j) ..              sum(i, x(i,j)/60993*100) =l= Afsaet_max(j);
      y1_con(i,j) ..              y(i,j) =l= x(i,j);
      y2_con(i,j) ..              y(i,j)*65000 =g= x(i,j);
      production_sum(j) ..        prod_sum(j) =e= sum(i, x(i,j)) ;
      quality_con(j) ..           sum(i, Kvalitet(i,j)*y(i,j)) =l= 0.15*sum(i, x(i,j)) ;


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