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Virtual products can be used for optimisation

Data from CT scanned pigs are a reliable source for yield models and production planning.

3D images from CT scanning provide more information about the pig than traditional methods of dissecting with a knife. The engineer challenges the slaughterhouse worker. Known technology used in a new way provides data, allowing the slaughterhouse to plan with larger flexibility than traditional methods. With this, the slaughterhouses obtain a unique basis for utilising the carcasses in the best possible way.

By Eli V. Olsen, Niels C. Kjaersgaard and Marchen Hviid

New tools obtain optimal knowledge as a basis for optimal production. 3D-images of carcasses provide detailed knowledge of the carcasses to the slaughterhouses. This knowledge can be utilised to determine reference data for production plans and to simulate the value of an entire week's production as decision support for strategic considerations such as the consequence of slaughtering entire males.

Classification and value

The purpose of objective classification of pigs for slaughter within the EU is to obtain a common basis for estimating the value of the carcasses expressed as the weight and the percentage of lean meat (LMP) in the carcass (Commission Regulation (EC) NO 1249/2008). It is up to each slaughterhouse to use the measurement for settlement with the farmer, and it is also up to each slaughterhouse to take the value. Value reflects the supply and demand for quality products (Marcoux et al., 2007; Branscheid et al., 2011). In this context quality is primarily the absence of fat, which is why lean products have the highest market value. However, there are regional exceptions, as the production of salted, dried hams requires hams with a suitably thickness of subcutaneous fat.

Through the years, settlement according to value has resulted in a considerable quality improvement of the pig populations, an example from Denmark can be seen in Figure 1.

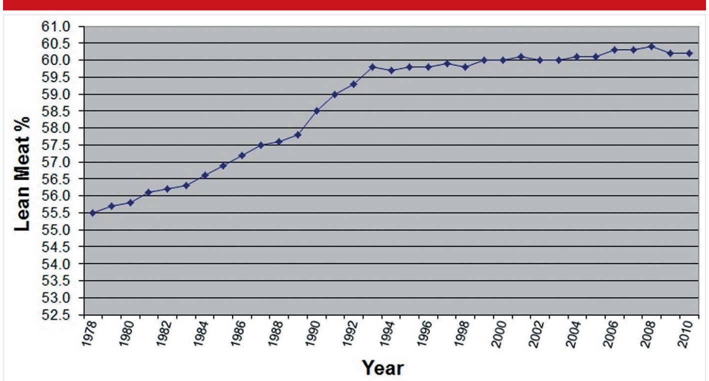


Fig. 1: Average lean meat % (LMP), in the Danish pig population 1978 – 2010.

The fat thickness above the muscle of the back is the most important indirect measurement for the meat content of the entire carcass, as there is a natural relation between the meat content and the fat thickness. By paying more money to pig producers that deliver lean pigs, the slaughterhouse has succeeded in motivating the producers to change the feeding and purchase breeding animals from breeding companies focussing on lean pig types.

A range of different measurement equipment can be used for classification. A common factor for all equipment is that they measure the meat content indirectly. This means that all equipment must be calibrated. A calibration describes the relation between indirect online measurements and a reference, and is determined by data from a representative sampling of carcasses. The lean meat percentage determined by dissection is the standard reference within the EU (Commission Regulation (EC) NO 1249/2008). Since 2008 it has become possible to perform the dissection by means of CT scanning (Commission Regulation (EC) NO 1249/2008;

Fig. 2: Preparation of the carcass before scanning

CAUSEUR et al., 2000–2004).

The model slaughterhouse Saerimner

CT scanning of entire carcasses provides completely new possibilities for extracting information from the carcasses e.g. the thickness of the subcutaneous fat, the position of the bones and the meat content in the cuts. The applications are illustrated by a model slaughterhouse, an imaginary slaughterhouse, in which actual CT data have been used to determine yield models and the value of the pig population.

As CT scanned carcasses, model pigs, can be used several times, we have called the model slaughterhouse “Saerimner“. In the Nordic mythology Saerimner is the name of a pig that the kitchen in Valhalla, the home of the gods, could prepare for the gods one day, and the next day the pig was complete again.

Pigs for Saerimner must be used for the product assortment for which they are best suited and which are demanded. This requires a production plan considering quality and price as well as limitations from measuring accuracy, sale and capacity.

Virtual product weights

The slaughterhouse possesses data from sampling of 400 carcasses (the same breeding material). Data consist of online classification measurements and CT scans of the entire carcasses except head and forefoot. These data have been used to calibrate the online classification equipment used to measure the lean meat % (the EU reference) (Commission Regulation (EC) NO 1249/2008). Below is described how data can also be used to determine reference data for models to predict product yield and quality.

Before CT scanning, the head and the forefoot of the carcass have been cut off. The tenderloin and the jowl have been cut out and placed at the carcass on a pillow filled with air (Fig. 2). The pillow filled with air cannot be seen in the scanned images, thus the tenderloin and jowl are easy to identify automatically at the scanned images (Fig. 3). CT scans consist of cross section images for each 10 mm in the longitudinal direction of the carcass. The images can be combined into a 3D-image of the carcass. In this way, a cross section image can be formed in the longitudinal direction of the carcass, a topogram as shown in Figure 4. By means of automatic image analysis (ERBOU, 2008; VESTER-CHRISTENSEN, 2008) the dividing lines are identified between ham, middle piece and fore end, indicated by the yellow and the red line in figure 4.

The dividing lines are based on the position of 6 anatomical landmarks. 4 points are used to align the carcass and to identify the primal cut position, and the remaining two points at *Tibia* and head of *Tuber Calsis* are used to cut off the hind foot in the joint.

This definition corresponds to the Ess Food cuts 1301, 1401 (1601+1801) and 1501 (Ess-Food Product Catalogue).

The three tissue types, meat, fat and bone are separated in the CT images. The CT images, e.g. Figure 3, represent a slice of the carcass with a thickness of 10 mm. In this way each pixel in the image can be regarded as three-dimensional voxels (volume pixels). The number of voxels corresponding to a given tissue type is a measurement for volume. In combination with the density, D, the weight can be determined and the total, virtual weight is given by:

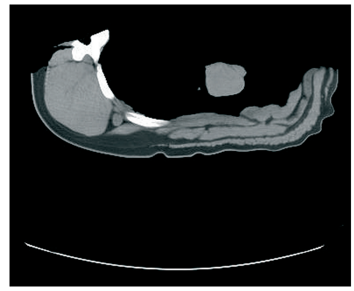


Fig. 3: The tenderloin “floats” in the CT scanned image

[1] Virtual weight = $D_{meat} \times V_{meat} + D_{fat} \times V_{fat} + D_{bone} \times V_{bone}$

The grouping into only three tissue types, meat, fat and bone, may seem too simple, however, it corresponds to the traditional apprehension of how a carcass can be dissected, and it is the procedure approved for virtual dissection. The voxel solution used ($1 \times 1 \times 10$ mm^3) is considered to be an acceptable compromise between precision and cost. The weight of half a carcass can be determined with a precision of approx. 100 g (VESTER-CHRISTENSEN et al., 2009).

The procedure mentioned above is part of a software module, PigClassWeb. As a starting point, the dividing lines between the cuts are determined as described above. The user can adjust the dividing lines enlarging or reducing the middle piece. The cutting instruction is automatically transferred to all model pigs in the database, and the average weight distribution is shown at the screen, while all details are entered into a data file. (Fig. 5).

Cuts and products from the

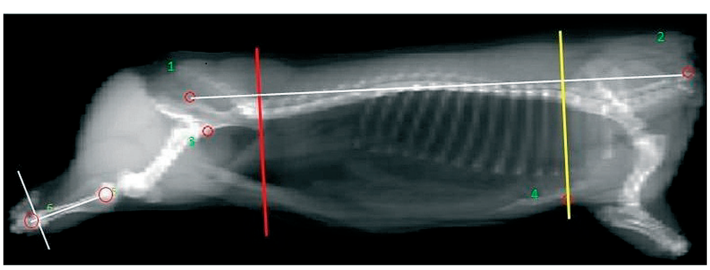


Fig. 4: CT scan of a carcass shown in a topogram.
1: Top of aitch bone; 2: Top of 1. neck joint
3: Ham point; 4: Fore knuckle.

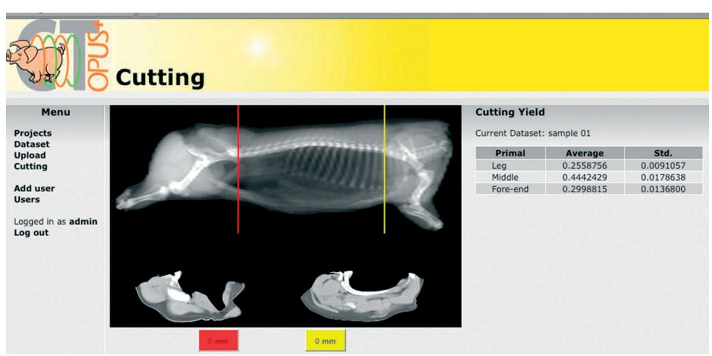


Fig. 5: The Software module PigClasWeb. The user can adjust the dividing lines, and the cutting instruction is automatically transferred to all model pigs. A data file is formed containing weights and yields for each model pig.

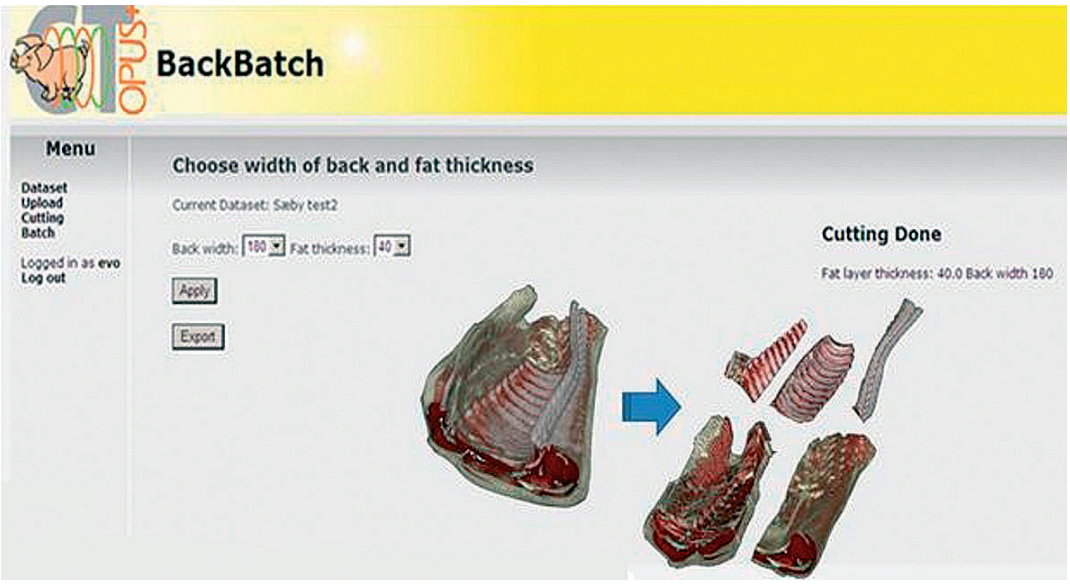


Fig. 6: Virtual cutting of products from the middle piece. The width of the back and the thickness of the fat layer are determined by the user and transferred automatically to all model pigs. A data file containing detailed information on weights and yields is created.

carcasses differ between countries. In Saerimner the middle pieces are divided lengthwise parallel to the *vertebrae*. The corresponding virtual cutting can be performed by the software module BackBatch. The user can determine the distance of the dividing line from the splitting line as well as the thickness of the subcutaneous fat. In this way, different product assortments can be produced. If the distance from the splitting line is chosen to be 20 cm and the fat thickness to the maximum (no cutting of rind or fat), back bacon with fat appears, the corresponding belly without bones, and the undercut ribs divided into two parts (spare ribs) and the "string of pearls" . Figure 6 shows an example of this virtual cutting.

However, if a dividing line is used corresponding to the muscle width and a fat thickness of 2 mm, a back muscle is obtained with 2 mm fat layer, belly without bones also with a fat layer of 2 mm, the same bone products as before, together with the cut off fat. For each adjustment/virtual cut, a data file is created with detailed results for each model pig.

Saerimner produces two different ham products, entire hams and ham muscles including by-products. The product weights of the two ham products are estimated in the detailed results from the tripartition with PigClassWeb.

Yield models – product calibrations

The weights of the cut out products – determined by the CT-scanning – are related to online measurements by classification equipment. That means relations like:

[2] Product weight = $constant_0$ + $constant_1$ x lean meat% + $constant_2$ x slaughter weight

Then the expected product weights can be calculated for all carcasses for which lean meat% and slaughter weight have been measured.

Special calibration of classification equipment with separate reference data

In some cases, a more detailed description can be obtained by calibrating the classification equipment against specific quality measurements (Hansen, 2009). Below two examples can be found.

The distribution of fat and meat in the middle piece is difficult to quantify. However, by means of CT images, as shown in figure 7, a trained quality employee can grade each middle piece as a reference for the bacon quality.

Similarly, specific subcutaneous fat thicknesses can be measured at the CT image and a quality reference can be determined for the ham, e.g. the thickness of the subcutaneous fat in an anatomically determined position (Fig. 8).

Fig. 7: CT image of a cross section of the middle piece

Calculated population value

Saerimner's product assortment is shown in table 1. In this context, a range of products is a combination of the fore end, middle piece and ham products (including by-products), such as F2, M2, S3. For some of the products there are quality requirements. One of the quality requirements concerns maximum fat thickness and product weight, another requirement is the suitability of the middle piece for bacon production, which depends on the fat distribution. In table 1, only the main product for each utilisation is mentioned, but the utilisation also includes by-products. The price stated is the average price for the entire part, and the price is stated as relative kg prices (units of value). The possible sales intervals are stated with a minimum and a maximum sale. For the products M1, M2 and S1 there will furthermore be a price deduction, if the quality requirements are not met. The deduction in price covers the expenses of further manual handling to approach the demands, smaller yield (more by-products) and possible a lower price as a consequence of not meeting the quality requirements.

Consider a carcass, for which the lean meat% is measured to 58 and the slaughter weight is 90 kg. The thickness of the fat above the muscle of the back is measured as 14 mm and the bacon quality is predicted to be quality 3. In principle, the carcass can be used for all combinations of products, but the quality requirements mean that some of the utilisations are not optimal. Consider e.g. the utilisation of M1, which is an entire middle piece that has to weigh less than 13 kg.

The expected weight of the middle piece is calculated with a formula of type [2], e.g.:

[3] Weight of the middle piece = 1.95 – 0.08 x lean meat% + 0.20 x slaughter weight
(RMSE = 600 g; $R^2 = 0.85$)

When the measured lean meat% = 58 and slaughter weight = 90 kg is inserted into the formula, the weight of the product is expected to be 15.3 kg. Thus, the utilisation of M1 is not optimal as the weight is too high.

The quality of an entire ham (S1) depends on the thickness of the subcutaneous fat. The expected thickness is calculated by means of the measured thickness above the muscle of the back, e.g.

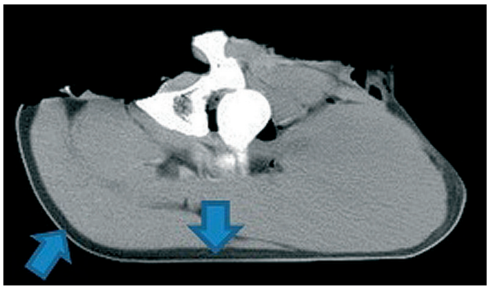


Fig. 8: CT image of a cross section of a ham indicating measurement spots

[4] Fat thickness of the ham = –5.3 + 1.34 x fat thickness above the muscle of the back (RMSE = 2,6 mm, R^2 = 0.61)

When the measured fat thickness above the muscle of the back – which is 14 mm – is inserted into the formula, the expected fat thickness above the ham is 13 mm.

The weight of the ham is predicted to 13 kg with the formula:

[5] Weight of ham = –3.1 + 0.06 x lean meat% + 0.14 x slaughter weight (RMSE = 360 g, R^2 = 0.88)

The value of the carcass for assortment F1, M1, S1 is

[6] $\text{Value}_{F1,M1,S1}$ = 2 x (9.9 kg fore end x 70 + 15.3 kg middle piece x (110 – R_1) + 13 kg ham x (100 – R_2))

R_1 and R_2 indicate the cost of production, when the applied carcass is not optimal for this purpose. R_1 and R_2 are both 10 for the carcass in question, and a value of 6786 value units is obtained for the carcass.

For the alternative F1, M2_quality2, S3 the value is:

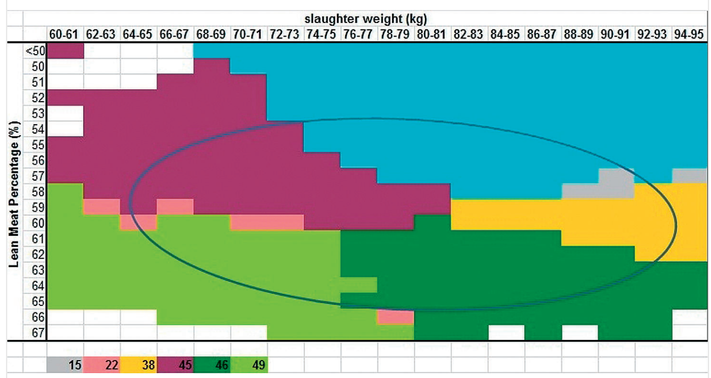
[7] $\text{Value}_{F1,M4,S2}$ = 2 x (9.9 kg fore end x 70 + 15.3 kg middle piece x (105 – 0) + 13 kg ham x (95 – 0))

The value of the carcass by this utilisation is 7069 value units.

Optimisation and optimal utilisation

The calculations are used for the production of an entire week. The value of the population for the week can be used as decision support for the production management, e.g. to compare the value of different strategies for sorting/utilisation of the carcasses.

Saerimner will apply each carcass for the product assortment that provides the largest value of the total production of the week. To control the utilisation of the carcasses towards this aim, the slaughterhouse uses sorting. Data from production from only one day or a week quickly becomes comprehensive, and the planning of the optimal utilisation becomes difficult to assess. But the optimisation problem can be expressed as a mathematical model that can be solved with commercial software as e.g. GAMS (General Algebraic Modeling System) . Examples of this can be found in KJÆRSGAARD (2008) and KOLDBORG JENSEN and KJÆRSGAARD (2010).



Source: KJAERSGAARD et al. Fleischwirtschaft International 6/2012

Fig. 9: Sorting plan for Saerimner

The utilisation of each carcass is limited to sales and demand, thus decisions will be made for the individual part that is not optimal for the carcass viewed separately, but is optimal for the total production. Table 2 shows the result of an optimal solution for 10 pigs from the total production. The optimal use of the parts is marked in bold. Please notice that the optimal fore end product for carcass 4 is F2 (value: 1290), even though a lower price is obtained than by producing F1 (value: 1505). The reason for this are the sales demands, demanding that at least 30% of the fore ends should be used for production of F2. By producing F2 from carcass 4 the "loss" is smaller (value: 1505 – 1290 = 225) than by using e.g. carcass 1 (value: 1762 – 1510 = 252).

Saerimner is capable of handling 7 sorting groups defined by means of classification data, which are the measured lean meat% and weight. In figure 9, the 7 groups are shown in colour. Most carcasses possess classification data within the marked ellipse. The dark purple and dark green areas define the main utilisations. The most heavy and fat carcasses are best suited for the product assortments marked turquoise and yellow, while the light and lean carcasses are best suited for the range marked pale green.

Potential

Saerimner have strategic considerations concerning sorting and with that the dimensioning of the chilling room and logistics: Will it be advantageous to introduce more sorting groups? As basis for decisions, a simulation is used of the production of the slaughterhouse. The simulation is based on model pigs, where each model pig is assumed to represent a number of almost identical pigs. The data base with 400 model pigs thereby can simulate a week's production of e.g. 6,000 pigs. The model pigs can be cut into all product assortments shown in table 1, and the "true" value of each cut can be calculated.

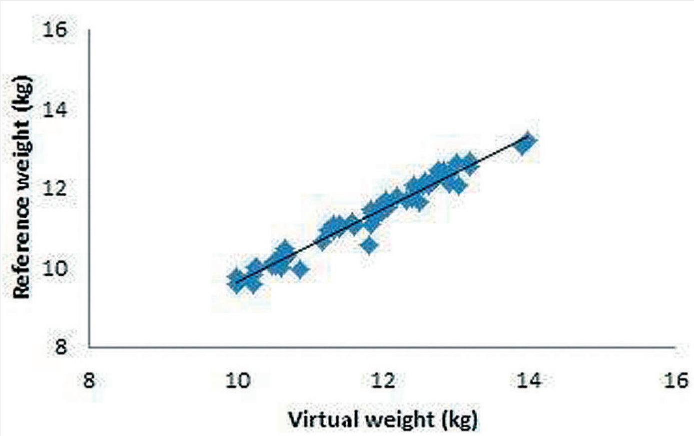
Saerimner's product assortment is practical oriented

Tab. 1: The slaughterhouse Saerimner's products assortments with matching quality demands, expected sale and price

Products			Quality demands	Sale %	Price per kg (unit of value)
Fore end	F1	Deboned and derinded[1]	–	30–70	70
	F2	Entire	–	30–70	60
Middle piece	M1	Entire	Weight < 13 kg	10–15	110
	M2	Bacon cuts	Quality 1	30–60	115
			Quality 2		105
			Quality 3		100
			Quality > 3		90
	M3	Deboned back & belly[1]	–	15–40	95
	M4	Entire	–	10–50	90
Ham	S1	Entire	< 15 mm fat, < 10 kg	40–60	100
	S2	Entire	–	15–40	90
	S3	Deboned and derinded[1]	–	15–40	95

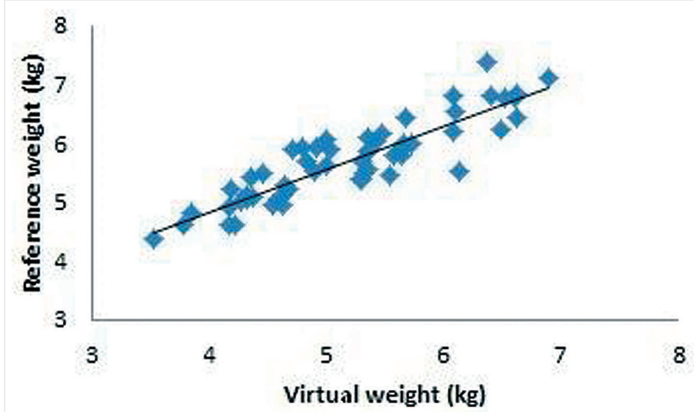
[1] = Muscles and by-products

Source: KJAERSGAARD et al. Fleischwirtschaft International 6/2012



Source: KJAERSGAARD et al. Fleischwirtschaft International 6/2012

Fig. 10: Relation between virtual and actual (reference) cut of ham



Source: KJAERSGAARD et al. Fleischwirtschaft International 6/2012

Fig. 11: Relation between virtual and actual (reference) cut of belly without bones

The potential is defined as the difference in value of the 6,000 simulated pigs with two different production plans:

- No sorting, meaning that the carcasses are used in the order they are slaughtered and the same amount is produced of each product.
- Optimal utilisation, meaning that it is assumed that the slaughterhouse has complete information on the quality and value of the carcasses and can use them without logistic, capacity or sales limitations.

In the model example, the potential is estimated to be 7.2%. In practice there are a number of limitations, which is why the value of using the population optimally, given these premises, will possess a value that is between the two production plans mentioned above. In the current example of 7 sorting groups and limitations as mentioned in table 1, the maximum production value is 3% lower than the potential value with optimal utilisation. Furthermore, it has been calculated that the value of increasing the number of sorting groups from the chosen 7 is less than 0.15%. It is possible to make more optimisation models that can simulate the effect of different decisions, e.g. other market prices or changes in the population (KJÆRSGAARD, 2008).

Discussion

Reliability of measurements – virtual cuts

The credibility of the calculations depends on the precision of each factor. In a representative sampling of approx. 60 Danish pigs, the virtual product yields have been compared with the result of actual cutting yields. Figure 10 and 11 show two examples of comparison of virtual and actual product weight for entire ham and belly without bones. In both cases, the correlation exceeds 0.9. But the weight of the ham is predicted with a standard deviation of 21 g, while the weight of the belly is predicted with a standard deviation of 50 g.

The deviation in precision is caused by the ham cut being much easier to define than the belly, both for the model pig and in practice. The uncertainty can therefore be ascribed to both the reference weight and the virtual weight.

Reliability of measurements – calculation of expected yield

The most important uncertainty points are related to the precision of the classification, and the relation between the classification and product yield. The weight of hams can be predicted by means of lean meat % (LMP) and slaughter weight with a prediction standard deviation = 360 g, while the middle piece can be predicted with a prediction standard deviation = 600 g.

Reliability of measurements – online measurement

The weakest link is clearly the limited information of the carcass, obtainable by known classification equipment. The formal demands to measurement precision that are made in the EU regulations (Commission Regulation (EC) NO 1249/2008) are that the meat content must be determined with a prediction error of less than 2.5 lean meat % units. If the population deviation is in the order of 3.5 lean meat % units, as in e.g. Denmark, then the ratio between the population variation and the prediction error ("signal to noise ratio") becomes very poor (NISSEN et al., 2006).

Reliability of prices and market demands

The value calculations depend on the accuracy of the prices and on the sales intervals for the different uses of the parts being realistic. In the calculations, weighted historical prices or expected prices can be chosen. In the same way, the price

Saerimner obtains the knowledge for optimal production

Tab. 2: Examples of calculated product value (index figures) of 10 carcasses used for all product assortments. Utilisations that provide an optimal weekly production are marked in **bold**.

	Fore end		Middles piece				Ham		
	F1	F2	M1	M2	M3	M4	S1	S2	S3
Carcass 1	**1762**	1510	3339	3005	**3172**	3005	2327	2327	**2456**
Carcass 2	**1633**	1400	2857	**3000**	2714	2571	2227	2227	**2351**
Carcass 3	**1694**	1452	**2858**	2598	2468	2338	2213	2213	**2336**
Carcass 4	1505	**1290**	2727	2727	2591	**2454**	2147	**2147**	2266
Carcass 5	**1701**	1458	**2640**	2520	2280	2160	**1991**	1792	1891
Carcass 6	1538	**1319**	2816	**2957**	2675	2534	2107	**2107**	2224
Carcass 7	**1723**	1477	2752	2752	2615	**2477**	2293	2293	**2421**
Carcass 8	1476	**1266**	2701	**2836**	2566	2431	2037	**2037**	2150
Carcass 9	1492	**1279**	2936	2642	**2789**	2642	2012	**2012**	2124
Carcass 10	1488	**1275**	**2626**	2387	2268	2148	**2141**	1927	2034

Source: KJAERSGAARD et al. Fleischwirtschaft International 6/2012 deductions as a consequence of lacking fulfilment of the quality will influence the calculations.

Reliability of simulation – potential

The estimate of the potential of detailed knowledge to the individual carcasses is based on a simulated weekly production determined by a sampling of model pigs. Naturally, the quality of the simulation depends on whether the sampling represents the actual weekly production regarding size, fattening degree, carcass composition etc. The present experience shows that a random sampling of 400 – 500 model pigs is sufficient to simulate a homogeneous pig population.

Strategic considerations

By means of a representative sampling of CT scanned carcasses – model pigs – an entire daily or weekly production can be simulated. The simulations can be used to analyse the size of the unutilised potential in an actual production with a number of necessary limitations. Subsequently, requirements can be made to e.g. the precision and measurement quality of the classification equipment in relation to the costs. An example can be found in KJÆRSGAARD (2008), in which the consequences of a general change in slaughter weight, logistic limitations in the production, e.g. limited capacity in the chilling room, and the complexity of the production plans are calculated. In the example shown above, the maximum potential at optimal production is estimated to be 7.2%. Furthermore, it can be calculated that the value of increasing the number of sorting groups from the chosen 7 is less than 0.15%, while a reduction to e.g. 4 sorting groups will reduce the value by 0.85%.

Recently, the model pigs have been used to examine the difference in yield between entire males and castrates. The fore ends of the entire males are significantly larger than the castrates and the backs smaller (KJAERSGAARD and HVIID, 2012). This problem is most interesting as the EU as well as a number of countries is working towards a termination of surgical castration of entire males. In this connection the data base was extended by 50 model entire males.

Conclusion

All slaughterhouses need to plan the production and sort carcasses so they can be used most efficiently, a task which is very comprehensive in large production units. The result depends on the quality of the available data. This article shows that virtual products, produced by data from CT scanned pigs, are an efficient method to obtain reference data for yield models and production planning, and as input to simulations and as decision support for strategic considerations like the introduction of more sorting standards.

Optimal utilisation of complete information on all carcasses in a homogeneous pig population is estimated to have a value approx. 7% larger than the value of a production, in which the knowledge of the carcasses is not used. The value of a concrete production depends on the homogeneity and production limits of the pig population, including price and market conditions. A data base with representative model pigs has furthermore been used to show that entire males have significantly larger fore ends and smaller backs than castrates.

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Authors' address

Eli V. Olsen, Niels C. Kjaersgaard (corresponding author: nck@dti.dk) and Marchen Hviid, Danish Meat Research Institute, Maglegaardsvej 2, 4000 Roskilde, Denmark

Eli V. Olsen, MSc, PhD, has been employed at the Danish Meat Research Institute since 1980 . Recently she is a senior consultant working with project management both on national and international projects for the meat industry with emphasis on statistical evaluation of measurements.

Niels C. Kjaersgaard, MSc, PhD, has been working with the DMRI since 2004. He is a senior consultant working in the fields of consequence analysis and optimisation of the raw material utilisation of pigs, fish and within bio refineries.

Marchen Hviid, MSC, started her career at the Danish Meat Research Institute in 1989. Today she is working as a senior scientist in measuring systems and has conducted several projects about measuring of carcass and quality in beef and pork, with requirements from the consumer and the possibility to fulfill the requirements by different measuring techniques.