AUTOMATION –THE MEAT FACTORY OF THE FUTURE

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Introduction

For many years, slaughtering has been industrialised with respect to organisation, work specialisation and use of production lines. Interestingly enough it was from seeing the conveyor systems used by the slaughter industry that Henry Ford got the inspiration to implement car assembly lines in the beginning of the last century. One could claim that the meat industry is now taking inspiration from the robot assisted and computer controlled manufacturing systems applied in the car industry.

So what is driving this development after decades of limited change in the technological development of slaughter processes? The industry benefits significantly from automation: one of the most important benefits after increased labour productivity is the improved working environment. Slaughtering, cutting and boning operations are very labour intensive and require hard and repetitive work. For many young people a job in a slaughterhouse is therefore not their first choice. This situation could be changed by automation, which will not only remove arduous work but will in addition introduce more interesting jobs in terms of planning, supervision and control of the new technology. Automation will also improve the hygiene and thereby the food safety by less manual product handling and cross contamination between carcasses because the tools in the machines can be cleaned more effectively between each carcass. Product quality and yield may also be improved, and the production recipes may be changed instantly in accordance with information on market demands.

The poultry and fish industries have implemented automated processes with success and, in New Zealand in particular, the lamb slaughter industry has been progressive in developing and using new technology. Only in recent years have many processes for pig slaughter and deboning been conducted by newly developed robots. The status of this development will be reviewed here with the Danish program for automated slaughter of pigs as a case. Regarding beef, the development in technology for the slaughter process has been quite limited partly due to the biological variation in animals and the cost/benefit of applying complex technology. Some of the potential options for R&D will be suggested here.

The option to replace operators with equipment may create benefits for the industry, particularly when the efforts put into the implementation of the machines are duly considered.

Automation development methods and procedures

Development of automated solutions for slaughter, cutting and boning is a complex task because of the biological variation, the complexity of the material to be processed and the variety of professional disciplines involved. In order to control project economy and progress the Danish Meat Research Institute (DMRI) has applied a staged development model comprising a number of distinct phases:

- Phase 0. Initiation
- Phase 1. Generation and evaluation of ideas
- Phase 2. Method development
- Phase 3. Experimental machine
- Phase 4. Prototype machine
- Phase 5. Production version machine
- Phase 6. Project evaluation

Projects for automation are carefully selected on the basis of their cost/benefit. During the idea generation phase, different teams are competing to identify the best solution. All projects are conducted individually by separate project teams with representatives from the industry and participating suppliers and manufacturers attached. The transition from one phase to the following phase includes both economic and technical criteria for decision of whether to proceed or not. One of the decision tools is a cost/benefit analysis combined with an investment analysis in order to justify whether the solution is still economically feasible for the industry or whether the project should be terminated.

The development work is supported by use of the most contemporary and advanced tools: CAD-tools for mechanical and electronics design, robots for initial testing of tool operations and simulation in combination with CT-scanned models of the products to be processed. The latter can be illustrated by the machine for round cutting of the hind legs.

The process involves cutting of the tail bone, trimming of fat at the tail head, groin meat and fat. A new CT-scanner is used for the development process. A large number of hind legs are scanned with high resolution (1x1x2mm) to form a catalogue, representing the variation in the Danish pig population. In the catalogue the variation of the joint is described in principal components. The analysis reveals the shape variation with respect to the anatomical fix points used for gripping the product. This shape variation can then be used to design the tool in an optimal sense, based on the catalogue.

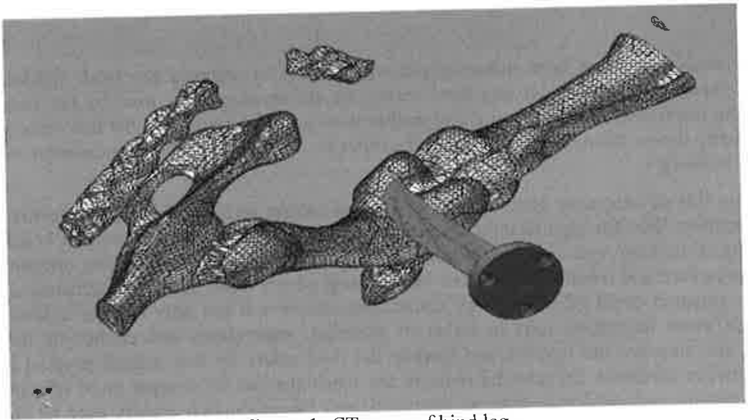

Figure 1: CT- scan of hind leg.

An automated pork slaughter line

The DMRI started development of new technology for optimal welfare during lairage in the late 80's and stunning of pigs in groups in the late 90's (Zink, 1995). During slaughterhouse lairage, the pigs can be moved by automatically driven gates. This means that today the pigs may be transported unstressed in homogeneous groups all the way from the farm until they are CO_2 stunned prior to sticking. The pigs are stunned in groups of 5-7. The groups are lead into a pater noster gondola which is lowered into the CO_2 where the pigs loose consciousness prior to sticking. The result of this, besides optimal animal welfare, is a mortality for slaughter pigs during transport and lairage which has remained below 0.2 $^0/_{00}$ for more than ten years. Furthermore, the drip loss in the meat is lower.

Most of the first part of the unclean slaughter line has been automated for decades with respect to scalding, dehairing, singeing and scraping. Only in recent years has it become possible to conduct more processes for slaughter and deboning using machines.

Modern pork slaughter lines in the EU run at 200-400/hour. In Denmark a line speed of 360/hour is usual whereas line speed in the USA is more than 1000/hour. The Danish pork industry launched an automation development strategy in 1998. The total investment in development exceeds €40 million and is organised in more than 30 individual projects which are in different stages of development. The aim is to automate a major part of the processes on the slaughter line and several cutting and boning operations. This was driven by expectations of better competitiveness, the high labour cost and an expectation of lower labour supply. In 2007 it will be possible to equip a slaughter line with 10 machines and a manning approximately 50% compared to the manual operation. The machines involved in such a slaughter line design are illustrated in Figure 2 with the present state of development indicated. In Figures 3, 4 and 5 photos of selected machines are given followed by the operations they perform. The hygienic advantage of the machine is that all tools are cleaned thoroughly between carcasses.

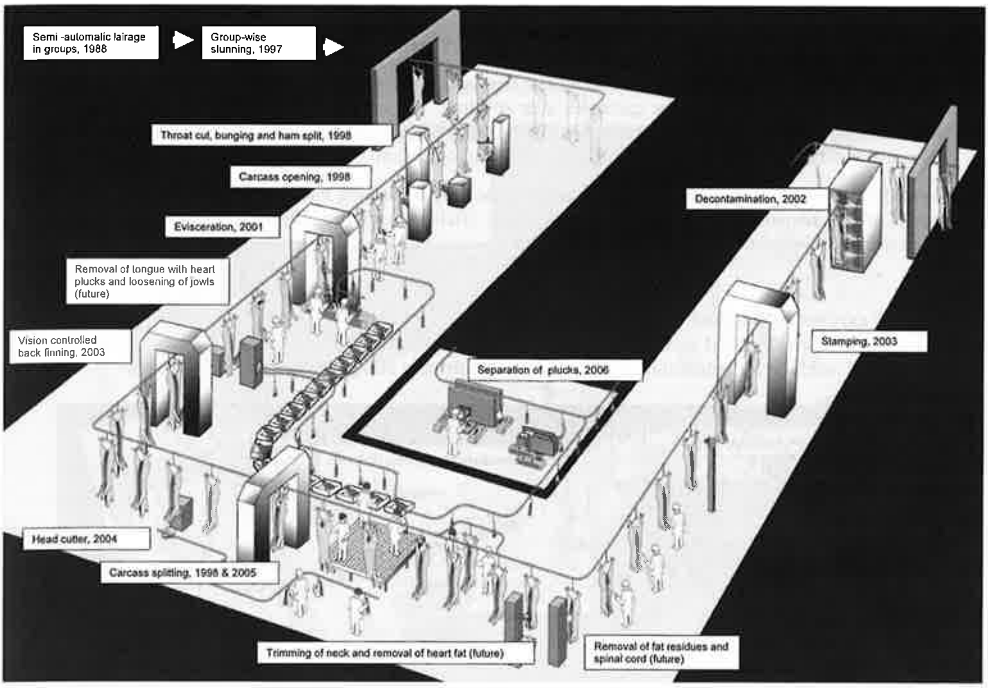

Figure 2: A slaughter line of 360 pigs/hour can be equipped with 10 automated machines and staffed with approximately 50% compared to a manual operation. The task of the machine is given in the textbox with the year of availability. Examples of machines are shown below.

Figure 3: Evisceration.

Figure 4: Head Cutting.

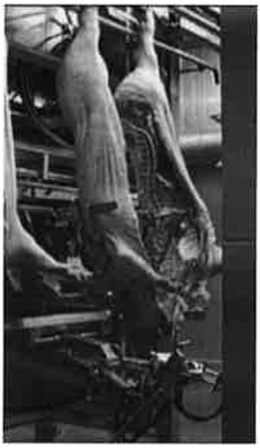

Figure 5: Trimming of neck and removal of heart fat (experimental machine).

Evisceration: The evisceration machine cuts the diaphragm, tears off the flare fat and loosens the intestinal tract such that the entire set of intestines and organs are removed from the carcass prior to separation, Anon. (2001). Because the separation takes place outside the carcass it can be performed more safely and the risk of faecal contamination is reduced.

Head cutting machine: A new machine for automatic cutting off of entire heads was recently introduced at some Danish slaughterhouses. The machine operates in two modes. It can either cut off the head entirely and leave it on a separate conveyor system or alternatively the machine can cut the neck only and leave the head hanging at the carcass by the jowls. Cutting off the heads before carcass splitting reduces the risk of contamination from the mouth and throat regions. The machine also provides better yield by leaving more neck meat on the carcass.

Trimming of neck, removal of heart fat and cutting off the foreleg: This machine, still in the experimental phase, will automate some of the critical cleaning of the carcasses after splitting. The machine automatically trims the neck region for glands and blood residues and from the breast part it will remove the heart fat. Finally the machine will cut off the forelegs. This cutting will be done more precisely than in a manual operation.

When the planned development program has been completed the only remaining manual tasks on a clean slaughter line will be removal of the sexual organs, separation of viscera, trichina sampling, freeing ends of tenderloins, final trimming and veterinarian inspection.

Automation of pig carcass cutting and deboning

As shown in Figure 6 below, the first process in the cutting department is usually to cut the tenderloin from the half carcass. A robot based machine for automation of this process is currently being developed.

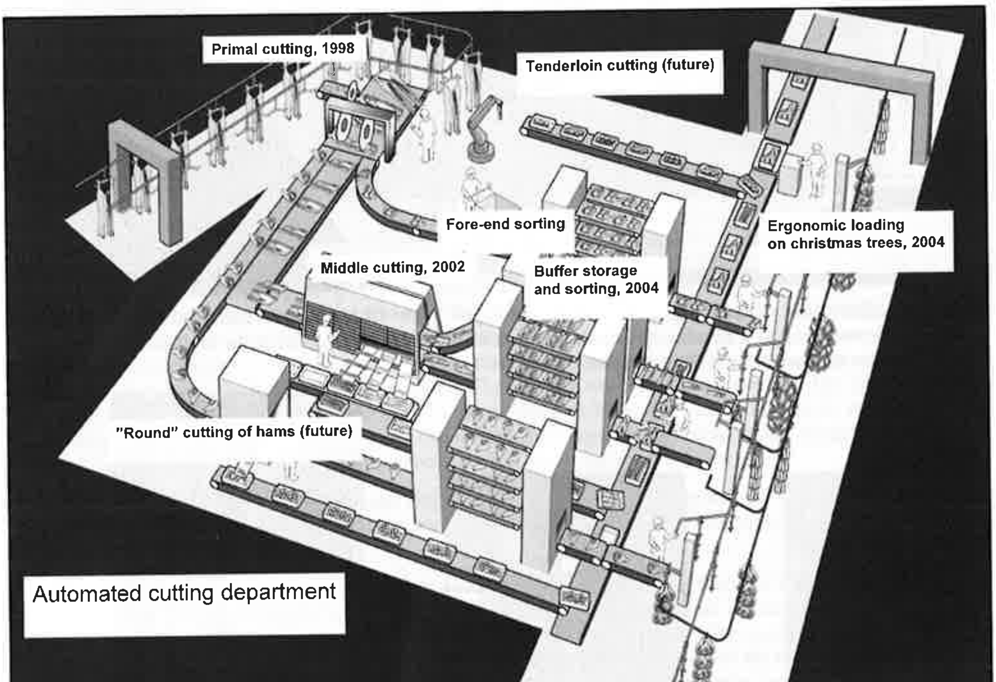

Figure 6: Example of design of an automated cutting department.

In 1998 a machine for *automatic carcass cutting* was introduced. The machine separates the half carcass into the three primal cuts: fore-end, middle and hind leg by sawing after precise measurements and positioning.
After carcass cutting the middles and the hind legs are conveyed to cutting machines while the fore-ends are moved directly to a buffer storage and sorting device.
The middles are processed in a machine finished in 2002 which cuts off the rib tops and separates the loin and the belly. The economic benefit of using the machine comprises savings on labour costs as well as added value by enhanced yield, because sawing of the rib tops can be more accurate and the division of the loin and the belly can be optimised according to the product specifications. From this machine the loins and bellies are moved to the buffer storage.
The hams will be processed by a new machine still in the experimental phase. The machine will automatically remove the tail bone and perform round cutting of the ham.
In the buffer storage the different cuts will be sorted according to customer specifications such as weight class, lean meat content, thickness of the fat layer *etc.* The cuts now arranged in quality classes will be loaded onto Christmas trees by means of a semi-automatic device, which will ensure that heavy lifts are avoided.

Automatic boning of fore-ends

Traditional boning of fore-ends requires a large number of operators and is a strenuous operation. In the future two types of machines – one for the removal of surface bones and one for the removal of interior bones - will be available for automatic boning of fore-ends and result in approx. 40% less operators, Figure 7.

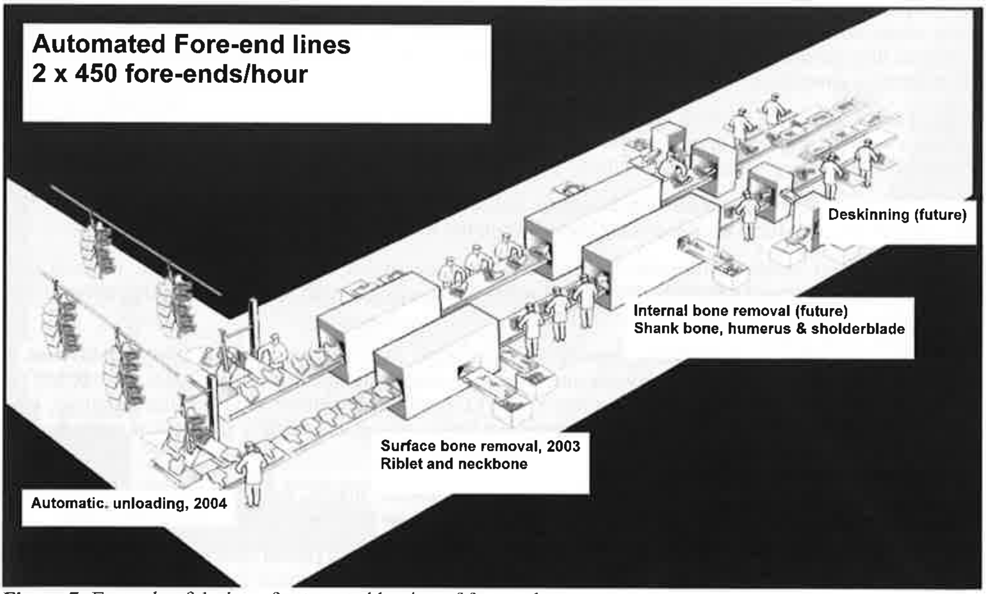

Figure 7: Example of design of automated boning of fore-ends.

The machine for removal of the surface bones - neck bone and riblet - was developed by DMRI and Townsend Engineering (Hansen, 2004). A number of these machines have been installed at Danish Slaughterhouses since 2004. The machine works at a rate of 450 fore-ends per hour and can be operated by one person (Figure 8). A further 2-3 operators carry out final trimming of the boned fore-ends. Very precise and powerful tools make it possible to cut closer and more uniformly to the bones. The machine thus improves the yield gain compared to manual boning.

Figure 8: Surface bone removal fore-ends.

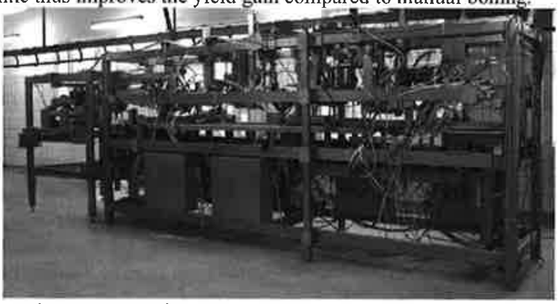

Figure 9: Experimental model for internal bone removal in fore-ends.

The other machine for removal of the interior bones - shank bones, humerus and shoulder blade – is currently being developed by DMRI also in cooperation with Townsend Engineering. The machine is designed for flow boning, *i.e.* the fore-end is moved through the machine without stops at a rate of 450 fore-ends per hour.

The machine has been divided into three sections: entry, loader and processing. The fore-ends arrive at the machine with the shank end first and the rind downwards (Figure 9). After boning the fore-ends will leave the machine in one piece and continue for trimming, defattening and skinning. The machine replaces operators, and the yield is almost as good as that which can be achieved in manual boning.

Automation of beef slaughter

Slaughter procedures for cattle have been rather stable for decades and only limited technological development has taken place. Most of the development has been in the area of manually operated tools which have been improved to ease the physical work for operators or tools developed for improving the hygienic quality of slaughter.

In the USA, high line speed in excess of 300/hour is achieved by dividing processes across more operators and by ensuring that the animals slaughtered are relatively homogeneous in size, as slaughter lines are specialised for steers and heifers. Several pieces of equipments are duplicated and processes are divided across several machines, *e.g.* hide pulling. These plants run in several shifts.

The majority of cattle in the world are, however, still slaughtered at lower line speeds. In the EU, most of the larger plants run in single shifts at line speeds from 30-75/hour and the plants are seldom specialised but must slaughter all types of cattle as they are delivered (Figure 10). This implies that new technology must be flexible and match a large biological variation in dimensions.

Presently the situation is that the EU-beef industry is dominated by few new slaughter plants and many older slaughter lines on which a variable degree of upgrading and renovation are going on. A declining production, over capacity and ongoing structural changes imply that new investments in R&D have been limited.

Slaughter must mainly take place regionally due to welfare and zoonotic issues as well as geographical constraints. This implies that a high labour productivity is necessary, and to obtain this it is necessary to invest in new technology.

The benefits for the beef industry with more automation options are similar to that of the poultry, fish and pork industries with goals of increased efficiency, better food safety and hygiene as well as a better working environment. For retail packaging, the needs are identical.

Given that individual companies and industry organisations are simply too small to undertake a larger R&D task, it seems necessary to join R&D investments between interested parties internationally. This will reduce the risk and the individual financial contribution and ensure a better match with EU market requirements and better market access. Joint R&D must involve a critical selection of potential projects that have a reasonable payback time and/or result in other direct advantages (hygiene, ergonomics, food safety).

The processes most relevant for automation of beef slaughter depend mainly on labour costs and legislative requirement. In a joint Scandinavian study, the following areas suited for automation have been identified:

- Automatic splitting and removal of the spinal cord (SRM) in one process (spinal cord removal is likely to be a permanent requirement and involves several operators, Figure 11)
- Automatic bung cutting, neck and breast opening, and removal of head and tail. (more processes may be carried out with different tools in the same robot, Figure 12)
- Automatic separation (cutting) in hind and forequarter (*e.g.* ongoing R&D between e+v and Banss)
- Cleaning of dirty hides prior to slaughter (a manual equipment from SFK/MLA may be automated for cleaning of belly, Figure 13)
- Automatic hide pulling (this process is critical with respect to hygienic slaughter and carcass presentation)
- The area of boning still needs a thorough analysis, but preliminary evaluations show an interesting cost/benefit as well as documenting that the physical strain for boning operators doing piece work is extremely high.

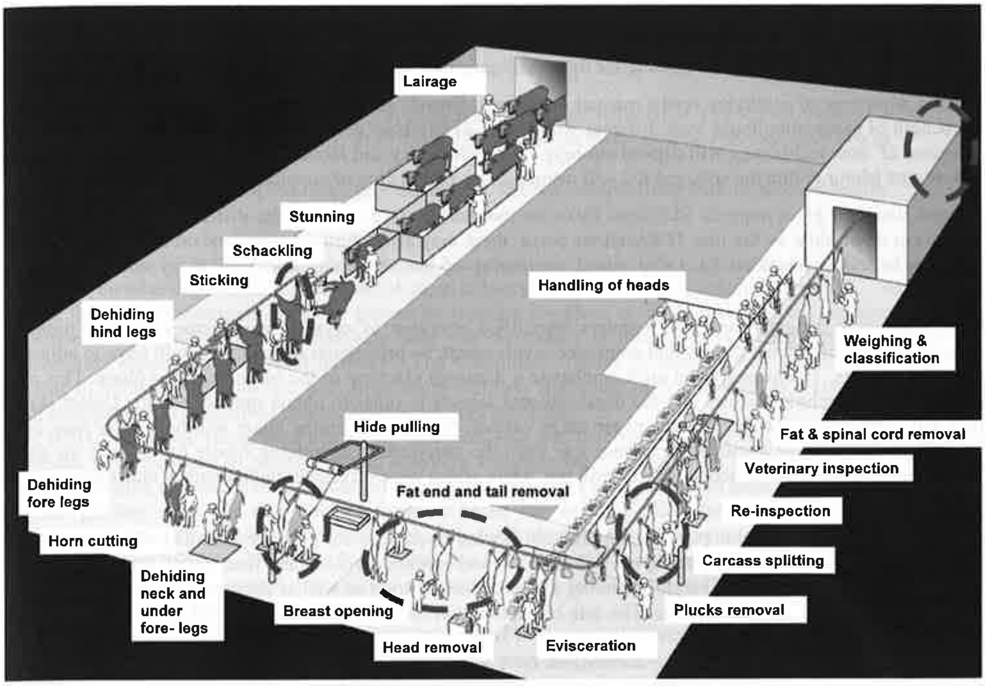

Figure 10: Traditional beef slaughter line with potential automation areas marked.

Some of the machines suggested are illustrated in Figures 11, 12, 13.

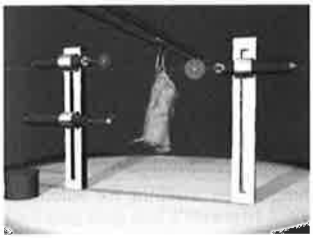

Figure 11: Splitting and spinal cord removal.

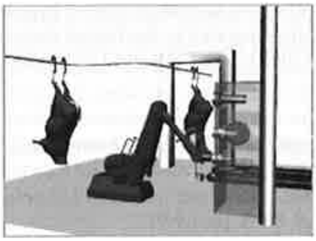

Figure 12: Automatic bung cutting, neck and breast opening, and removal of head and tail.

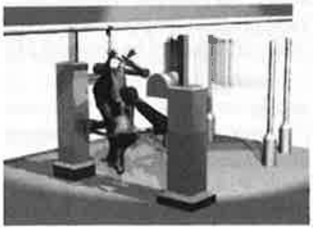

Figure 13: Automatic dedagger for cleaning the belly before dehiding.

Preliminary cost/benefit analysis of some of the machines above shows a pay back time of 3-6 years when doing one or two shifts per day. Considering that it is a complex and risky R&D process it is necessary that a sufficient market for machines is ensured and that the R&D cost can be carried by several interested parties. In addition the R&D project should aim to qualify for support by the technology platforms under the 7th EU framework.

Benefits and barriers and automation

It is important that automation is driven by an improvement in competitive strength. This means that it is a prerequisite for a successful commercialisation of the developed machines that they can be paid back within a short time frame, often as low as 3 years for meat industry investments if the production economy is the only parameter considered. The R&D investment to get a machine ready for the market is high, and market penetration and recovery of the R&D investment may take time.

Therefore substantial development will require a long term strategic decision, and international cooperation between the meat industry and the machine suppliers. Because of the risk and time profile of the R&D investments involved it will be of major importance to obtain public funding for this development.

The economic advantage of machines versus manual operations depends strongly on labour wages. For example, the economic benefit of automation looks very different with wages of €10/hour compared to €20/hour which implies that the introduction of new technology will depend strongly on the efficiency and labour market conditions. For example, access to low cost labour within the enlarged EC will influence the exploitation of automation technology.

An automated slaughter plant requires additional focus on monitoring the quality of the different processes to avoid quality defects or down time on the line. If deviations occur, these may affect further operations on the line on the next machines. This is solved by either increased visual monitoring by the remaining operators or by automatic vision systems.

A well run high tech slaughter line also requires intensified attention to organisational issues such as training, cooperation between professional groups and employee involvement, so production management will have to adjust to new values and policies. The management must emphasise a thorough planning of the commissioning phase. This plan must address both the technical issues and the organisational aspects in order to obtain optimal results. Unless skills, motivation and preparations for the technology are taken care of, the commissioning phase will be long or may even end up in failure. This is a well known experience *e.g.* from the introduction of milking robots for cows in the dairy industry, where some farmers returned to manual milking, while others were successful with identical machines.

Conclusions

Machines for automation of a major part of slaughter and boning operations for pigs are now available and provide competitive advantages and a better working environment, animal welfare, hygiene and food safety as well as yields. Their successful introduction requires careful planning of the implementation as well as attention to new organizational values and policies to reach the full benefits. The rate of exploitation internationally will depend on the labour market situation and international competition.

For beef slaughter, some potential areas for automation have been identified. As the beef industry structure is more fragmented and the development will be complex and resource demanding, a strategic R&D effort is likely to require cooperation between several partners to share the development investment and ensure industry relevance.

Acknowledgements

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