

# Meat Industry 4.0: A Distant Future?

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## Implications

- The meat industry had experienced a significant transformation over the past century and more so over the past 25 years.
- Automation can now be seen in both primary and secondary processing of meat, but implementation depends on factors such as cost, and availability of a labor force.
- Currently, there is accelerated development in areas such as machine vision and robotics to replace more manual operations in meat processing plants.
- We already see smart meat factories, where conductivity and information are used to control certain operations.

**Key words:** automation, industrial revolution, meat industry, processing, robotics

## Introduction

Automation has catalyzed a significant transformation in the meat industry of many countries in the last 25 yrs. Overall, the meat production chain is complex and affected by many factors, starting with breeding, moving on to farming (e.g., type of housing, nutrition, and veterinary treatments), transportation of animals, primary processing, further processing, and distribution to the end consumer. The focus of this review is on automation in the primary and further processing areas. Still, examples related to progress on the farm will also be provided (e.g., automated feeding, traveling robots used to monitor barn conditions). Improvement programs within the meat industry are multifactorial. Usually, they take over a decade from start to finish (e.g., breeding to improve beef meat tenderness and implementation of automated meat cutting).

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Today there is still quite a lot of variation in the degree of automation, where small meat plants usually rely on manual labor, and large ones invest more in mechanization (note: this also depends on geographic location, labor cost, and availability). There are also apparent differences between the primary processing of poultry, red meat, and fish. The two stages, known as primary and secondary processing, also vary. The latter deals with much more uniform raw material, and therefore fewer people are needed. [Figure 1a](#) shows an example of fully automated equipment that can produce 200,000 identical nuggets every hour.

It is interesting to look at progress from the perspective of time, and attempting to explain the activities in a modern meat processing plant to a person that lived 2,000 yr ago; e.g., a Greek soldier. If we can bring him to a modern plant, he will understand all the necessary steps associated with primary processing, which include stunning, removing feathers/scales/hides, evisceration, washing, and cutting. He could have performed all those tasks with the sword he was carrying. However, it is not going to be easy to explain to him how products move at high speed on a motorized conveyor belt, data captured remotely and then presented on a computer screen, or robots used for cutting meat and packaging. The same will be true if we try to explain the process to a person that lived more recently. If we look at paintings from the medieval time, we can see the necessary steps of meat processing, by a person that today is called a butcher. Often the drawings show beef/goat processing, where the animal is hung by its hind legs from the ceiling, and the butcher is cutting portions of the meat on a wooden block. This is still the image that many of our customers have in their minds today. However, a more realistic presentation of the inside of a modern meat plant is shown in [Figure 1b](#), where conveyor belts, surfaces made of stainless steel and plastic, and electronic equipment (e.g., scales) are seen. Today there is a lot of emphasis on sanitation, where meat-processing plants have various mandatory procedures to assure food safety (e.g., washing and sanitation every few hours, with specially formulated chemicals, dipping knives in hot water between cutting different carcasses, steam pasteurization, and acid washes of eviscerated carcasses).

Another example to illustrate the high degree of automation in modern meat processing plants is the equipment currently used to slice meat ([Figure 2](#)). The machine uses laser scanners to provide the computer with a 3D image of the cut (chicken fillets, in this example) and together with the overall weight and



**Figure 1.** Modern fresh and processed meat plants (a) fully automated forming line, capable of producing 200,000 identical nuggets per hour; (b) in line automated sorting at a fresh poultry processing plant. Courtesy of Marel.

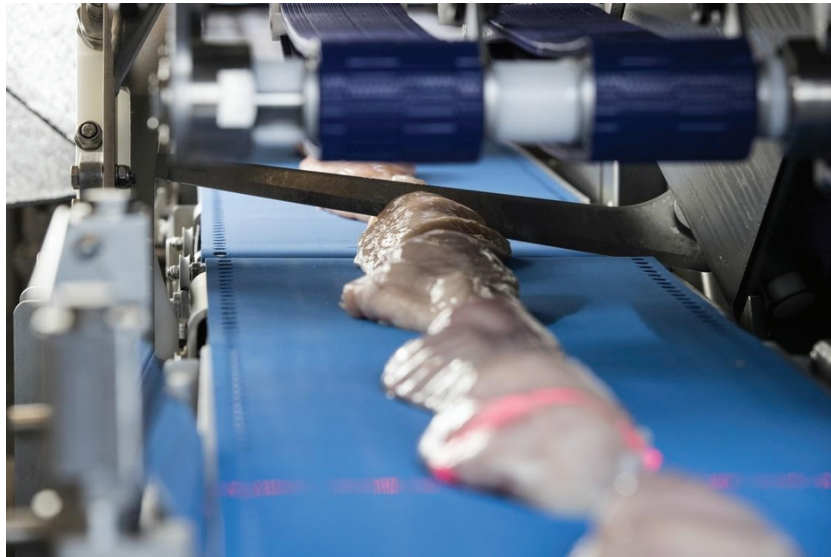
estimation of the fat covering (i.e., to adjust for volume and density differences), the computer controls a high speed, rotating blade to cut fixed weight portions. The knife can perform 700 cuts/min, with an extremely high degree of accuracy ( $\pm 0.5\%$ ). The development of such equipment is an example of a successful joint effort among meat scientists, mechanical engineers, computer scientists, and machine vision technicians. This machine can perform the work of dozens of Greek soldiers or modern meat processing plant employees, at a much higher accuracy, speed, and sanitation level.

### Our Fast-Changing World

Our surroundings are rapidly changing today with the introduction of computers, social media, online shopping, and medical imaging. It will be difficult to explain to the Greek soldier how, for example, laser scanners are used to create the 3D image of the meat cut (Figure 2), electricity moving via wires, and use of the wireless internet to transfer information. The Greek soldier might think that he is standing in front of the Oracle in Delphi as information passes wirelessly from one location to another. Humanity has gone through a journey full of developments over the past 3,000 yr, with an accelerated rate over the past 200 yr. Today we talk about the four industrial revolutions to describe these past 200 yr. The first revolution

was the introduction of mechanized equipment powered by steam. The second was marked by the introduction of mass production with the help of electrical power (e.g., the development of the first assembly line in a meat processing plant in Cincinnati around 1870). The third revolution was marked by introducing electronics and computers to automate production. Today, some segments of the meat industry are moving quickly towards the fourth revolution, where cyber-physical systems with virtual interlinking appear on the market (e.g., high-speed automated meat cutting equipment relying on various sensors; selling meat on the internet at international auctions; virtual modeling of cooking, and chilling processes designed to enhance food safety).

In the past, the meat industry used to be quite conservative in terms of adopting modern technologies; today, it embraces new technology at a fast rate, as described below. One major driver of innovation is the exponential increase in computer power, which can be demonstrated by the tremendous increase in the number of transistors on a computer chip over the last 50 yr. In 1960, there were about 10, while today we see smaller and much more efficient microchips with  $10^6$  transistors. A few other interesting statistics: typical power went up from a few watters to over 100, and the number of logical cores from 1 to 80. In his 2017 book “Thank You for Being Late”, Thomas Friedman describes this phenomenal explosion of technology



**Figure 2.** Computer-controlled meat portioning, using automated weighing and laser scanning (see the red line at the front) to get highly accurate target weights at a very fast speed (up to 700 slices/min). Courtesy of Marel.

by using Moore's Law, which says that we have seen doubling the microchip's power every 2 yr for the past 50 yr. [Friedman \(2017\)](#), compares the first 1974 Intel microchip (#4004) to the 6th generation chip that has 3,500 times faster performance, is 90,000 times more energy-efficient and is 60,000 times less expensive to produce. He continues to say that if the Volkswagen Beetle (the most popular car built) would have shown the same advancements, it would theoretically travel at 300,000 mph, cost \$0.04, would run  $2 \times 10^6$  miles/gallon, so you will only need one gas tank for the lifetime of the car (although Moore's law is not talking about the rules of thermodynamics). Other examples include the Uber taxi company that today is the largest in the world and did not exist 20 yr ago. The other amazing fact about Uber is that although it is the largest company, it owns no taxis! The same is true for Airbnb, Google, and Facebook. Friedman further discusses General Electric's business model, where a substantial portion of its growth today is derived from hooking up machines with computers and sensors. By doing so, they are developing a big market for what is called preventative maintenance. Hooking up sensors to windmills that generate electricity, locomotives, and jet engines allows GE to provide a maintenance schedule to avoid catastrophic engine failure before expensive parts are damaged. Friedman estimates that today only a small amount of equipment is hooked up to computers ( $\approx 1\text{--}2\%$ ), and this is going to be a booming market (e.g., home fridges sending Amazon a list of items to deliver). Some meat processing plants are already using this technology, where data collected from sensors measuring the performance of a deboning machine in the Far East, are evaluated in real time in Europe.

### Global Meat Consumption/Production

Meat consumption is predicted to increase, and poultry is expected to surpass red meat (in 2017, poultry 120 Mt, pork

118 Mt, beef 70 Mt, and in 2027, 140 Mt, 130 Mt, and 78 Mt, respectively ([OECD-FAO, 2019](#)). It is also projected that meat production will increase by 50% by 2050. Most of the growth is predicted in the Asian market, and poultry is expected to become the main source of meat. Some of the reasons for that include the efficient growth of broilers, competitive feed conversion ratio, and less religious barriers. It is also important to understand how income is affecting meat consumption around the world. Overall, as people earn more money, they move from a cereal-based diet to an animal protein-based diet. In a country such as Vietnam, increasing the GDP from US \$ 1 to 4 resulted in raising annual meat consumption from 10 to 50 kg/capita, whereas in the United States increasing GDP from US \$ 100 to 120 did not have an effect ([Ritchie and Roser, 2019](#)). Another interesting prediction is that in 2050, food demand is going to increase by 13% per capita. This is related to people becoming taller and heavier, and therefore requiring more kilocalorie per day (the average person in 1975 was 161 cm tall and weighed 56.7 kg, in 2014 the numbers went up to 163.1 cm tall and 64.7 kg ([Vásquez et al., 2018](#)), and this trend is predicted to continue. It is also important to emphasize that some of the recent studies on meat consumption and health show that red meat consumption—in moderation together with other foods—is beneficial to the human body ([Valli et al., 2019](#)). This particular meta-analysis evaluated >150 studies involving over 6 million people, emphasized here, as there have been some publications claiming that red meat consumption can be detrimental to human health.

### Changes in Meat Production and Consumption Patterns

Over the past century, we have seen substantial changes in the way meat and meat products are prepared and consumed. Today a large number of fast-food restaurants, supermarkets,

and gas stations are selling prepared food. In the past, people used to mostly rely on food preparation at home. Today eating out or buying prepared food represents a significant portion of food consumed, e.g., >50% in places such as North America. This can also be demonstrated by, for example, the proportion of poultry sold as whole bird vs. cut up and further processed products. In 1965, 83% of the broilers were sold as whole birds, while this currently only accounts for about 5% in the North American market. Instead, 60% is sold as further processed products and 35% as cut up/portions (National Chicken Council, 2011). The proportion of fully prepared products is increasing as consumers have less time for cooking at home and more disposable income. It has been estimated that in 1937 the time spent on food preparation at a US home was 2.5 hr/person, in 1954—1.0 hr, in 1974—30 min, in 1990—15 min, and today it is about 8 min. Those reductions also correspond with the introduction of modern appliances in the 1940s, later in 1954 the introduction of prepared foods, 1974 marketing more frozen foods, and 2010 home delivery. Those changes have also created a considerable shift toward further processed meat products (e.g., heat and eat chicken nuggets). This shift has been good for the industry where higher margins are attained when selling branded, fully prepared products compared with fresh meat cuts sold as commodity items. During this transformation, the industry has also increased production speeds (Table 1) by introducing more automation. This table shows the progress in the primary poultry industry that increased speed from 3,000 birds/hr (bph) in 1970 to 15,000 bph today. Overall, poultry has the fastest lines today, but it should be noted that although red meat plants are slower (e.g., 1,400 pigs/hr and 400 beef animals in very modern plants), the meat weight processed per hour is usually higher than at a poultry plant. The ability to raise speed and volume is the result of developing fully/semi-automated equipment (e.g., cut up and portioning equipment).

When analyzing this progress, one should also recognize the significant advancements in improving livestock production. An example can be the changes in broiler production over the past 100 yr where the time to raise a 1.13 kg broiler was 16 wk, in 1920, with a feed efficiency of 4.7 and a mortality rate of 18% (American National Chicken Council, 2020). Today it takes 6 wk to raise a 3.00 kg bird with a feed efficiency of 1.7 and 4% mortality. These advancements have been due to learning and improving breeding, nutrition, husbandry, and veterinary

**Table 1. Advancements in line speed at primary broiler processing plants**

Year	Line speed	Automation
1970	3,000	De-feathering
1975	4,500	Evisceration
1980	8,000	Meat harvesting
1990	9,000	Electrical stimulation
2000	10,500	Cut up
2010	12,000	Unloading
2015	13,500	Deboning
2020	15,000	Portioning

Data 1970 to 2015 from Barbut (2015).

medicine. Similar improvements have been seen in the red meat industry, but not to the same extent.

The introduction of more machinery has helped to increase the efficiency and throughput of meat plants. An example from Agri Stats data shows that in 1995, each worker at a primary poultry processing plant was responsible for processing 210 bph, and this went up to 315 bph in 2014 (Donohue, 2014). Today a few highly automated plants even report a ratio of one person responsible for processing 580 bph (calculation based on production data divided by the number of workers on the floor). Systems such as in-line image analysis are helping the industry move to the next level. Figure 3 shows such a system, utilized to capture images of broilers moving in line at a rate of 15,000 bph (Figure 1b). Similar systems are available for pork, beef, and fish. The software later evaluates each frame and analyzes for conformation of the carcass, missing parts, size, and defects such as skin tears/bruises, to grade the birds. The software then decides to allocate each carcass for selling as a whole bird, or as portions. This gives processors a considerable competitive advantage, as they can select birds for each category they need (e.g., an order of 2,000 kg deboned chicken fillets), from a large pool of birds, and therefore optimize inventory use. Installing the system can be a substantial initial investment, but it pays for itself fairly quickly (e.g., 3 to 5 yr) and addresses the problem of labor force shortage. However, in places where labor is less expensive, and a large labor force is available, manual processing dominates the scene (e.g., large production halls filled with hundreds of people performing manual tasks ranging from evisceration to deboning). Yet in other regions of the world, wet markets still exist where individual animals are processed. However, they are slowly closing, and operations are moving to centralized processing plants to reduce risks (e.g., SARS, Covid-19 virus) and increase efficiency. The emerging situation with the Covid-19 (and past incidences such as SARS) results in companies accelerating the introduction of automation (Molteni, 2020). This trend also helps overcome challenges of finding and keeping a well-trained labor force (some of them also got sick during the pandemic), as well as demand for improved food safety, quality, and efficiency.

## Big Data in the Meat Production Chain

Big data is becoming more prominent in agriculture and many other areas around us (e.g., medicine, transportation, and social media). Newer and faster sensors, connected to various algorithms, are used to capture and process lots of data quickly, and then create summaries and action plans. An example can be a drone flying over a cornfield while capturing information with a camera sensitive to different wavelengths. The rate of data collection is measured in megabytes per minute and can include information about the height of the corn, health of the plant, and problems with insects/diseases. The data are then used to apply a chemical/fertilizer/water only to the area needed at a very early stage, saving time and optimizing resources. Another example is monitoring the health, growth, and productivity of milking cows, where each cow carries a chip



**Figure 3.** Image analysis system used to grade and sort broilers. Courtesy of Stork.

that records the amount of food it consumes (e.g., by linking it to a special feeding gate), body temperature, milk production, etc. This information is used for early detection of health problems, need to supplement the diet with specific vitamins/minerals, adjust the amount of feed, etc. In poultry barns, small robots are now moving around and collecting data such as temperature, relative humidity, ammonia concentration, posture of the birds, problems with feather pecking, and birds not moving around the barn. These data collected are used right away to control barn conditions and, if needed, focusing on a specific area for treatment before the problem gets out of control (e.g., wet litter in an area where a fan is not working).

In a meat plant, capturing the image of each broiler (Figure 3) creates a large dataset used for grading, defect tracking, decision-making about cut-up, and deboning; all allow management to maximize plant utilization and profit. The information can also be merged with real-time meat prices and take advantage of price variation, to improve marketing decisions. Similar systems are also available for beef and pork, where images of split carcasses are machine graded (marbling, fat thickness, and loin surface area), for estimating yield, pointing out defects (bruises), and later even monitoring genetic potential.

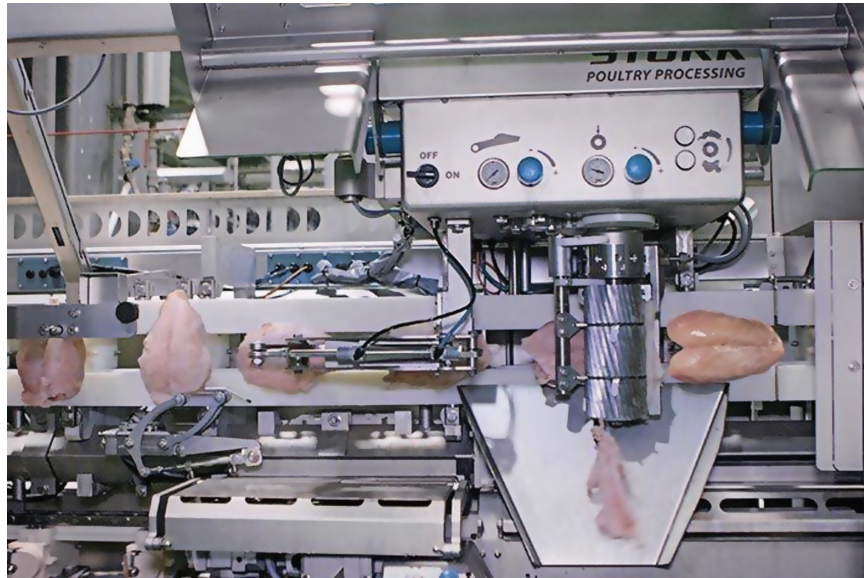
### Automation in Meat Primary Processing

Several manual tasks that used to be performed by people have now been automated. One of the first took place in the 1940s to 1950s and involved the automation of coating fish sticks (Barbut, 2015). In that case, it took a few years to overcome the challenge of uniformly applying batter and breading to fragile fish sticks in the secondary processing area. However, the primary processing area presents more significant challenges as animals vary in size, shape, orientation, and density of various tissues. For example, size variation within a broiler flock with

an average body weight of 2.5 kg, can range from 1.5 to 3.0 kg (100% difference). The same applies to a group of pigs, where an average carcass weight of 80 kg can have pigs weighing 60 to 100 kg. These variations affect the dimensions (length and width) and proportions of different cuts. Therefore, developing machines for cutting and splitting has not been such an easy task at the beginning. Today, with advancements in computer science, mechatronics, and sensors, developments are moving at a faster rate, and some of the meat industry's suppliers are exclusively focusing on robotics.

Figure 4 shows equipment for harvesting broilers' breast meat fillets. It represents the 5th or 6th generation of the equipment that was introduced about 25 yr ago. The new generation machines are more accurate, faster, and precise compared with earlier machines. The equipment can process about 3,000 fillets/hr and is capable of measuring the size of the breast bones (before cutting), therefore providing much better performance compared with older models. Note that each of these machines is covered by numerous patents that represent substantial investments by the manufacturer. It is also interesting to note that people are usually positioned at the end of the process and asked to finally detach the fillets from the bone; i.e., employing manual labor to check for bone fragments and any other defects.

An example from the beef industry is the equipment used to split the carcass into several primary cuts (Figure 5). In this case, a sensor first obtains an image of the skeleton/bones (e.g., by x-ray, ultrasound), and then directs a robotic arm equipped with a knife/saw to cut in a specific direction and depth (Guire et al., 2010). Producing an accurate image of the carcass is essential because of the significant variations in size and confirmation among animals, even from the same herd. It should be mentioned that the knife can also be equipped with pressure sensors, to prevent cutting into bones (e.g., can result in bone fragmentation, or even knife shattering; both are serious food



**Figure 4.** Automatic filleting equipment. <https://zootechnicainternational.com/news/worlds-firststamf-hd-breast-filleting-bigger-birds/>

hazards). These robots are rather expensive but can work 24/7, very accurately, in a cold environment, and replace dozens of employees. Because people are not present, the knife can be cleaned, in another chamber, with strong acids/boiling water after processing each carcass and by that raise sanitation standards. The use of such robots also eliminates repetitive strain injuries seen in people performing the same job many times each day.

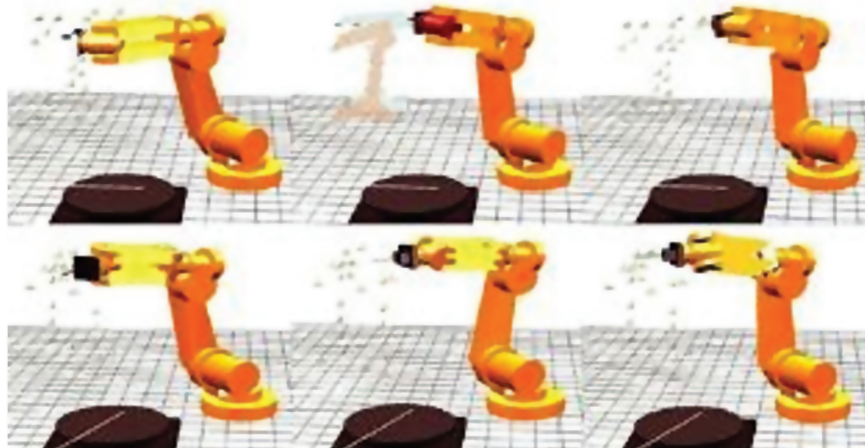
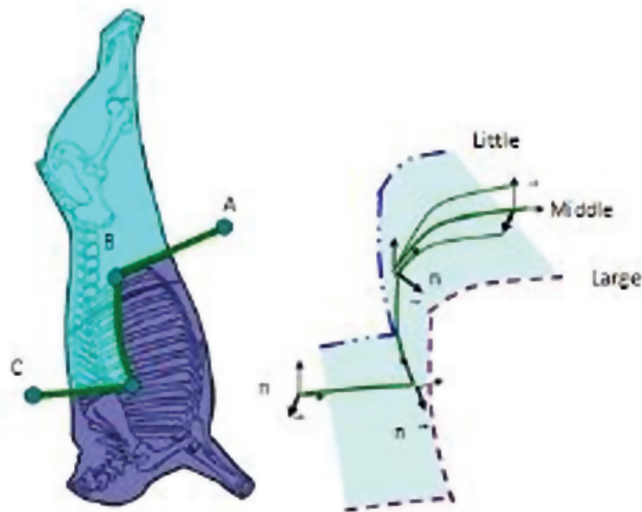
An example from the fish industry (Figure 6) shows a waterjet knife (operating by a focused, high-pressure water jet), used to automatically trim undesirable skin from fish fillets. Before cutting, the fillet is scanned (meat side up), data are processed, and the computer algorithm decides about the optimal trimming pattern to minimize waste. The fillet is then moved (on a conveyor belt) toward the water jet knife that is programmed to trim it. Again, this high-speed and accurate machine can replace dozens of employees, and work in a cold environment without any breaks.

### Automation in Meat Further Processing

As indicated before, more automation is seen today in this area because raw materials are more uniform or can be easily made to be more uniform (e.g., pressing a hamburger patty) compared with raw materials in the primary processing area. Three examples from different areas are provided as follows: (1) production of nuggets from beef/pork/chicken/fish meat; (2) in-line sausage casing application; (3) computer-controlled high-volume cooking operation. The first example is showing a forming machine (Figure 1a) capable of processing 4 metric tonnes/hr. When formulating 20 g nuggets, the device can produce 200,000 identical nuggets every hour. Today this is a fully automated operation where the meat batter is pumped into a forming machine and then discharge by either stamping out the

nuggets (high-pressure forming) or by pushing the nuggets out of the mold by a stream of air (low-pressure forming). These high-volume machines are very accurate (the mold's volume is predetermined), can work in a cold environment (to minimize microbial growth), and require minimal supervision (quality control technicians usually take samples every 1 to 2 hr). Some of these machines are also equipped with an automatic scale to verify the weight of each nugget and make instantaneous corrections. The machine can also be fitted with an image analysis system to automatically detect problems (e.g., misshaped product and binding of two adjacent nuggets). The use of low-pressure technology to release the nuggets from the mold is relatively new (Barbut, 2015). It has been a game-changer in the meat industry, as employing low air pressure (i.e., flowing from the back of the mold through porous/sintered metal) significantly reduces the pressure applied to the nugget (i.e., lean meat is composed of 70% water). It also helps to reduce meat waste, noise at the plant, and water use compared to high-pressure machines.

Sausage production used to be a very labor-intensive process where casings (natural, manufactured collagen, cellulose, or plastic) were brought to the plant and then manually fill, tied, and hung on a smokehouse tree. Furthermore, defects in the casings (e.g., holes in natural casings) would require stopping the process, cleaning, and readjusting the equipment. Over the years, newer filling equipment has been introduced (e.g., hydraulic stuffers, automated twisting, and clipping) that helped the industry reduce downtime. A more recent game-changer has been the introduction of the co-extrusion technology, where the casing is produced on top of the product as it is coming out from the stuffing horn (Figure 7). This allows the producer to use a higher level of automation and move away from the traditional batch type operation to a continuous process. Processors have a choice to either use a protein-based



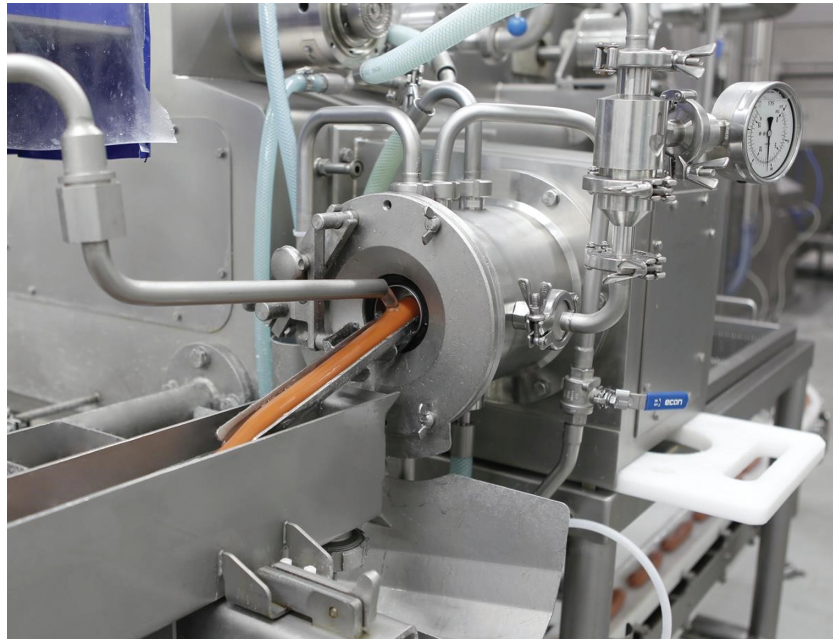
**Figure 5.** Illustration showing the principles of splitting beef hind and forequarter, also known as the Z-cut (Guire et al. 2010).



**Figure 6.** Automated fish trimming, using a water jet knife. Cutting pattern is controlled by a machine vision system. Courtesy of Marel.

casing (collagen), a hydrocolloid based ingredient (alginate), or a hybrid of the two. Both collagen and alginate are cross-linked shortly after extrusion (by liquid smoke, and calcium, respectively) to stabilize the shape of the newly formed sausage. There

are pros and cons for using each type of casing material—e.g., collagen provides better “snap” but requires a more expensive set up for fiber alignment to resemble natural casings (Suur and Barbut, 2020). As with the nugget forming machine,



**Figure 7.** In line, fully automated co-extrusion of sausage casings. Courtesy of Townsend.

the co-extrusion equipment can also be fitted with a scale to monitor each sausage link, and correct any small weight variation in real-time. In today's market of fixed-weight packaging, this helps to produce uniform size links, and avoid expensive give-away of product. The setup also allows improving food safety standards as processors can choose to use cook-in-the-bag technology. This can eliminate any post-cooking contamination risks (e.g., frankfurters produced in cellulose casings are stripped off the casings after cooking and before packaging, in a step that can expose them to cross-contamination from people, equipment, and the surrounding air).

Cooking a large volume of meat product presents various challenges in terms of efficient energy use, producing uniform color and texture, food safety etc. [Figure 8](#) shows a computer-controlled, high volume (7 to 8 tonnes/hr) spiral oven with two cooking zones. The spiral design helps to minimize the footprint of the equipment (at a premium in meat processing plants) while also making air circulation and cooking more efficient. Various sensors are sending information to the control unit used to precisely adjust air temperature, volume, and relative humidity in each of the zones (note: outside air temperature and relative humidity change throughout the day/season). Unlike home cooking, where a 5% to 10% difference in cooking yield is not noticed much by the consumer, a 0.1% variation in cooking yield in a large commercial oven can translate into hundreds of thousands of dollars profit/loss per year. Thus, precise real-time control of all parameters is essential when dealing with a large volume of products, as well as controlling CO<sub>2</sub> emission. The dual spiral design is used to control conditions in each of the two towers separately ([Figure 8](#)). For example, using high humidity in the first tower to heat the product without any weight losses, followed by low humidity and hotter air in the

second tower to provide the brown/golden color and crispy texture on the surface of the product.

## Integrating Animal Production and Meat Processing

One of the main focuses of the food industry today is to integrate all the steps in the supply chain. For the meat industry, this means tying up information coming from the farm to meat yield and quality. Several software programs are currently available to perform such tasks, and they are also helpful when it comes to traceability required by governments around the world (e.g., trace a cut of meat to a particular farm in case of a disease problem). An example of a segment of the system operating within a meat plant is shown in [Figure 9](#). The screen illustrates the use of information captured while monitoring the various steps at the plant, starting from live animal receiving to performing the various steps (e.g., evisceration, chilling, cut-up, deboning, packaging, and inventory in the warehouse). The use of such handheld devices (tablets and cell phones) connected to a software fed by hundreds of sensors is relatively new in the industry. Overall, it allows plant managers to oversee the whole operation in real time and make fast and accurate decisions. In the past, many written reports were prepared, summarized, and analysis would take a few days/weeks, so most actions were based on historical data. The advancements of in-line weighing stations, cameras, and image analysis systems ([Figure 3](#)) allows collecting a large amount of valuable data, including tracing meat cuts from an individual animal (e.g., fabricating a large beef carcass results in many cuts distributed to various places within the plant). Information from the different stations is fed to a central computer that provides a real-time snapshot of each section within



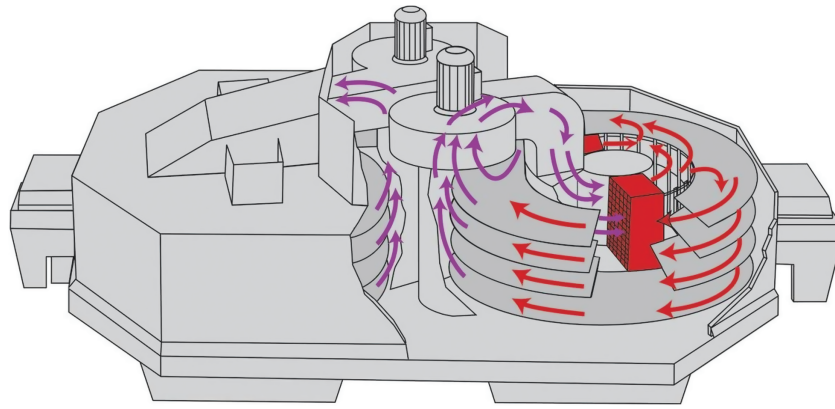


Figure 8. A computer-controlled twin tower (two zones) spiral oven. Courtesy of Townsend.



Figure 9. Real-time tablet presentation of the entire broiler primary processing plant. Data are collected from a wide range of sensors. Courtesy of Marel.

the plant. The system can also monitor today the efficiency of each worker cutting the meat on the line.

This system is an excellent example of Industry 4.0, where data are sent to the cloud and analyzed by artificial intelligence software, which then helps make decisions based on pre-determined criteria. Software and hardware installation costs money, but the payback is very significant in terms of cost savings in areas such as improving efficiency, traceability, waste reduction, plant utilization, and inventory control of perishable meat products.

Another area where such systems can help is reviewing the whole chain of fish harvesting, processing, and supplying consumers with fresh fish. In this case, a computer program can optimize planning for a fishing vessel going out to sea (to harvest wild fish in the ocean or a fish farm close to shore), on a certain date, for supplying a specific market on a particular

day (keeping in mind that fresh fish has a limited shelf life of a few days).

Increase raw material utilization is today another prominent issue for the meat industry. In the past, a single fish that was caught (a small-scale operation) and processed manually, resulted in only 50% to 60% of the carcass being utilized. Later, more dedicated meat processing plants were built, and more fish could be processed with better efficiency and slightly higher utilization. When the first fish mechanical deboning machine was introduced in the late 1940s (Froning, 1981), residual meat on the bones was harvested and provided 10% to 15% more edible material. Next was the introduction of processed fish products, such as fish sticks and breaded portions, which helped to utilize more minced meat. Today the goal is to use 100% of the carcass (note: there is a new Icelandic icon for 100% Fish that can be seen on the

internet) where gelatin, enzymes, and fish skins are used for cosmetics and medical applications (e.g., collagen sheets for burn victims). As society is looking at making agricultural production more sustainable, we can expect more innovations in the different areas of production, processing, and by-product utilization.

## Conclusions

Significant progress has seen over the last century and particularly over the past 25 yr in the meat industry. This has been possible due to substantial advancements in meat science, animal science, genetics, animal nutrition, welfare, engineering, and computer sciences. Developments helped to implement more automation in primary and secondary meat processing facilities, increase efficiency, and reduce manual labor (to address the labor shortage, skilled worker availability, and repetitive motion injuries). Advances have led the industry to move to greater capacity production; e.g., contributing to reduced production costs. It is interesting to note that today, relative meat prices are lower compared with 50 yr ago (adjusted to the cost of living index). We have also seen significant improvement in sanitation, food safety, and traceability and should expect more advancement in the future.

*Conflict of interest statement.* None declared.

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## About the Author



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