We need to rethink production technology for meat-packers—the old cutting table is being revived

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Implications

- Traditional production lines will become much less abundant, and robotic production cells will conquer the arena propelled by low cost and advanced sensors and artificial intelligence.
- A leap step is taken toward a production system operating 24 h 7 d a week with the first robotic production cell fabrication underway at a Danish meat-packing facility. Complex operations will be undertaken by a set of self-learning collaborating robots.
- Knowledge and self-learning algorithms will become an important asset on the meat-packers balance sheet. Existing technology will be disrupted, and first movers will get ahead of their competition: The moment for decision is coming close.

Key words: artificial intelligence, capacity utilization, meat processing, productivity, robotic automation, work environment

How We Ended Up Here

The wonderful story about Mr. Henry Ford visiting a Chicago slaughterhouse almost a hundred years ago is truly enjoyable. A meat-packers disassembly line inspired Ford Motor Company to organize its production in continuous assembly lines and sparked the industrial revolution further into higher efficiencies and fewer production flaws. The story makes people in the meat industry proud, and a visit to a modern slaughterhouse clearly demonstrates how far efficiency and productivity can be driven with sophisticated management systems, skilled employees, and highly specialized automation technology.

Of course, there are big differences among the various species of animals that are being processed. In general, the level of automation is higher, the smaller the carcasses are. Poultry processors are usually highly automated, whereas beef processors are much less automated. The same observation goes for the line speed, where poultry processors can handle 20,000 carcasses per hour, pig processors 750 per hour, and beef processors 300 per hour.

But the classical line production (see Figure 1) that we know from the meat industry is challenged, and there are several reasons for that. First of all, there is an upper limit to how fast a production line can run. To some extent, this is compensated by designing longer production lines with more people. If there is access to low-cost workers, it may work. But at a certain point, it will become unproportionally more costly to include more workers at the production line, because the consequence is longer production lines, which will increase costs per unit. Moreover, countries with access to low-cost workers are observing increasing salary costs and their particular production setup may risk becoming inefficient which drives the cost of production up.

Another reason is that it is becoming increasingly difficult to attract workers to the meat industry. The work environment is strenuous and often the salary is low. Other sectors offer more attractive jobs, leaving the meat industry with a big recruitment problem.

The supporting automation technology is yet another reason why we may see the end of line production in the meat industry (Barbut, 2020). Because line speed is very high in the slaughterhouses, the automation technology must be specialized and adapted to the extreme production conditions. That is costly and with a limited market size, the incentive to innovate may be too low. Moreover, the technology must be sufficiently robust for frequent sanitation which adds to the production costs.

On a more theoretical note, it can also be observed that the utilization of the automation technology is low and may be only 30% of the full capacity. This is the nature of line production due to the design. The automation technology is fitted to the production line and is awaiting the carcass to approach before the automation technology can perform the processing. Often the automation technology is standing idle a lot more than the processing time, and from an engineering point of view, this is highly inefficient and adds to production costs.

When a production line is running at full speed, it has a high productivity, but experience shows that it is not uncommon that...
a single incident along the line causes line stops frequently. An uptime less than 80% is not uncommon and sometimes even as low as 50%. This clearly demonstrates the vulnerability of classical line production and the extreme demand for uptime of the automation technology fitted to the line. Keep in mind that any modern slaughterhouse receives animals on an ongoing basis and that breakdown can be detrimental to the inflow of animals and the preceding logistics. Uptime is king.

So instead of designing the automation technology to fit the production line, why not design the production setup to fit the automation technology? We need to rethink the production design and it may well mean that we will reinstall the old cutting table where many processes were done by one operator in parallel instead of lines. In fact, this is exactly the development that the Computer Numerical Control (CNC) industry went through in the 1990s and that the automotive industry is going through more recently (Angerer et al., 2015)—migrating from classical line production into what we will call cell-based production. Many operations are performed in a cell with many cells in parallel contrary to the line production where one operation is performed at a time. A cell-based production in the meat industry compares to a very sophisticated cutting table.

**What Is Cell-Based Production**

Ideally, a production cell is a delimited area where an item is being processed by numerous operations. It can be done by people, but in this context, it is the application of robots that makes it relevant. A robotic production cell can consist of one or more robots that process the carcass with many operations (see Figure 2).

The robots will work simultaneously or even collaborate and ideally process an entire carcass including cutting and deboning. A robotic production cell is particularly relevant for larger carcasses due to the labor intensity and at this point lack of cost-efficient available automation technologies on the market.

Why are robotic production cells interesting? Part of the answer lies in the fact that it enables much more powerful innovation. Until now, the meat industry and their technology providers have developed costly specialized automation technology, but the application of standardized industrial robots opens the door into the huge innovation storm that takes place in assembling industries (Brogårdh, 2007). The automation technology can to a much larger extent rely on standardized industrial solutions at a much lower cost. Simply said, the technology providers to the meat industry will not anymore need to engineer complicated mechanized solutions but simply include best practice robots and instead focus on tools and control algorithms. The powerful robot innovation storm will have a natural inflow into the meat industry as well.

In the pig industry, kill lines are already automated, and it is likely that robotic production cells will be a next-generation choice for technology providers. But a little
further downstream, it has been almost impossible to automate the cutting and deboning areas. The product mix is high, production series may be short, and cutting operations are complex. In this situation, the robotic production cell is highly relevant and probably a feasible way to improve efficiency in this area.

Robotic production cells will be organized in parallel to match the needed capacity of the slaughterhouse; basically, redundant robotic production cells that can perform the exact same operations. This redundancy implies that the risk of total production stops is much lower compared with the classical line production. If one production cell breaks down, the remaining production cells can still function, and production will continue although with a lower capacity. This is a huge advantage compared with the present situation.

It’s All about the Algorithms

Establishing a robotic production cell is a big investment to any meat processor or technology provider. But the explosive development of technology creates a lot of tailwind. Sensors are key to the operation of the robots, and obviously, machine vision is an integral part of the function. The development is rapid, and cameras are becoming cheaper and more powerful year by year. Especially, three-dimensional-, Time-of-Flight-, and multispectral cameras are useful to give input to the robot control system in combination with tactile feedback systems (Kumar, 2018).

However, clever design of the tools mounted at the end-effector of the robots will make the entire operation much simpler. The correct choice of materials, design, and operation of the tools is the key to get optimal yields and correct product quality. Although tools are being designed as generic as possible to make sure that they can be used for several operations, they are still specialized to some extent. Therefore, more robots carrying different tools are needed. However, more robots are eating square meters, and there are never sufficient square meters available at the slaughterhouse. Automatic shift of tools is much preferred and will be a way to keep the footprint down of the robotic production cell.

In the end, vast amounts of data are being created, and the control algorithms must be able to handle them sufficiently fast to be able to control the robot. Developing algorithms will be the true shift of paradigm, because the algorithms will not only be hard coded for a number of operations, but it will also be self-learning and adaptive. Once in operation, the algorithm will be improved based on the ongoing production. It can learn gradually about how to cut to other specifications, and it can accommodate the biological variation among each carcass, meat cut, or in longer terms, species change over time.

The implications of this are huge because this is exactly what is needed to handle small production series and a complex product mix. Ideally, the robotic production cell can operate with an individual cutting pattern optimized for each individual item—a true hyperflexible production.

As algorithms are self-learning, they will eventually become adapted to the products and procedures of the slaughterhouse. They will become part of the critical knowledge base that any company tries to protect and that is often part of the company’s competitive edge. Moreover, the algorithms represent a powerful way to transform tacit knowledge into solid documentation. The algorithms can be duplicated and proliferated, and in an international production setup, this is a powerful way to create an aligned and high-quality production, where trained algorithms can be introduced into new robotic production cells anywhere in the world. Furthermore, the algorithms can be interconnected across robotic production cells, across production plants, and across borders—what a powerful learning system! Just like the roots of a tree. In a future not so far away, the algorithms may be the most important asset on the balance sheet.
The concept of robotic production cells may hold the key to a new cell-based production paradigm at the slaughterhouse. However, to turn the idea into reality requires acting. To this end, the development of the world’s first robotic cell for pig production (see Figure 3) at a Danish slaughterhouse has started with the aim to investigate the practical implications in a realistic setup (Philipsen and Moeslund, 2020; Wu, 2020).

As cell-based production completely disrupts the traditional line production, it is very challenging to integrate the robotic production cell into existing facilities. If it was possible to introduce cell-based production across the entire slaughterhouse at the same time, these challenges would of course not exist. However, the exploration of robotic production cells has only just begun, and a factory-wide installation is still very far away. A realistic path toward cell-based production will identify and replace parts of the traditional production line, and, therefore, solving problems related to integration is crucial. For this reason, the layout of the robotic production cell as well as the choice of products to be processed and how these will flow in and out have been considered. Six operations have been identified, all of which are carried out at the same location after the cold carcasses leave the chilling area and enter the primal cutting. The six processes are toe cutting, tenderloin extraction, ear cutting, stab wound removal, head cutting, and trisection. These choices make it feasible to install the robotic production cell in the existing production flow at the slaughterhouse.

For the tests carried out, the carcasses are brought directly from the production and arrive in the test facilities hanging on rails from the ceiling. The carcasses are taken down onto a conveyor that carries the carcasses into the robotic production cell. After the carcass arrives inside the robotic production cell, it is analyzed with sensors and cameras to extract relevant information. The six operations are then executed by several robotic arms in parallel using dedicated tools developed for each individual task. Everything is orchestrated by a software control system running on a powerful PC next to the robotic production cell. The software is completely modular with key components running on separate threads in parallel to take full advantage of the available computing power. The software structure provides maximal flexibility and makes it easy to be extended with new modules, for instance for additional algorithms, sensors, cameras, tools, or robots.
The core idea is to transfer the complexity from dedicated mechanical design to an intelligent software control system. This strategy keeps the cost down on custom machinery and adds the flexibility to reconfigure the system on the fly. It also drastically reduces the development time and facilitates the exploration of more innovative solutions for highly complex manual operations. The ongoing development at the test facilities is focused on intelligent control systems and smart tooling, including a generic fast tool change.

One of the main challenges is designing the intelligent part of the control system. The question boils down to how the relevant information is extracted from various sensor and camera inputs to guide the robots. The progress in research and development in artificial intelligence, in particular deep neural networks (LeCun et al., 2015), has made it feasible to introduce these algorithms in the automation solutions at the slaughterhouses.

Designing robust deep learning algorithms has always been difficult regardless of the application domain. However, the slaughterhouse takes the usual challenges to a new level due to the large variations in the input and the strict requirements on precision and capacity. Experienced butchers are both skilled and fast, and the individual processes are already highly optimized in the existing line production setup. Consequently, the algorithms must be very fast and extremely precise to make the robotic production cell a feasible replacement. The large biological variation and variations introduced from upstream processing by human operators or machines make this task extremely challenging.

In the robotic production cell, the algorithms are provided with images of the carcass recorded by several three-dimensional cameras located inside the cell. During initial tests, it was quickly realized that common off-the-shelf deep learning algorithms, for instance, based on semantic segmentation (Lateef and Ruicheck, 2018) or object detection (Liu et al., 2020) have difficulties meeting the requirements. To resolve these issues, a custom neural network architecture is embedded in the core of the control system. The design relies on many discoveries made during intense tests in the robotic production cell concerning all parts of the pipeline, from data collection and annotation strategies, network architectures, training methodologies, tool design, and cutting strategies. The resulting algorithms (see example in Figure 4) are robust, precise, and easily run in real time, adapting the cutting patterns to each individual carcass for all six operations under investigation.

Although several milestones have already been reached, many challenges still lie ahead. The robotic production cell test facility is a first attempt to bring the abstract concepts of multifunctional cell-based production into practice for the meat industry. The task is immense and, even when broken down into parts and solved one at a time, uncharted territory is explored for every step taken.

So, what is next? Sometimes it is forgotten that intelligent control systems only provide intelligent solutions at the moment of creation. Automation solutions degrade over time because developers cannot predict what will happen in the future. Will the carcasses increase in size? Or maybe new machinery upstream introduces new physical features on the carcasses? Preparing for the next step, the potential application of a range of online learning algorithms is currently under investigation, for instance, reinforcement learning (Francois-Lavet et al., 2018), which exactly addresses this problem. In fact, these technologies turn the situation upside-down. From the time the intelligent control system is installed, the quality will not degrade but instead improve. This happens through a feedback loop that analyzes the quality of the operations and based on this allows the system to self-optimize while running. The successful implementation will unleash some of the latest developments in artificial intelligence at the slaughterhouse.

**Technology Trends**

The digital development is so fast that even just understanding the new possibilities is a challenge. Everything becomes cheaper and Moore’s law (Schaller, 1997) is also applicable in...
this situation. Risk for the slaughterhouse is obvious that once
the capital expenditures are decided, the company is stuck with
the decision, and tapping into new technology may lead to a
loss of the investment. But the production paradigm with ro-
botic production cells is a bit different because a large part of the
technology is modularized and based on standard platforms. It
compares to consumer electronics where we are used to frequent
software updates for that will improve performance or add new
features this is also the case for robotic production cells. The Tesla
vehicle is a brilliant example of a platform that can be remotely
updated, and extra performance can be purchased as downloads
(Chen and Perez, 2018). In the near future robotic production
cells will recieve frequent software updates that will improve per-
formance and prolong the lifecycle of the investment.

But there is an even more important aspect especially when
it comes to capital expenditures and hardware. Hardware
updates, new tools, new functionalities, new sensors, and
so forth can be retrofitied in the cells. With the natural re-
dundancy in a setup with robotic production cells, the actual
retrofitting can be done simultaneously with production, and
no stops are needed. A robotic production cell should not
be looked upon as a complete machine but rather a versatile
platform that continuously can be improved and adapted to
new conditions.

The Business of Biological Variation

Most slaughterhouses are sorting carcasses based on value,
size, and other parameters. There are millions of dollars hidden
in correct sorting of the carcasses, which is basically to match
carcass composition with customer specifications and expecta-
tions. Modern slaughterhouses have big cooling facilities to
handle carcass variability. The reason is that the workers manu-
ally must cut to a certain specification based on the type of car-
cass that is being presented to them, and the only way to do that
is to sort the carcasses in a cooling facility before fabrication.

But that complexity disappears with the introduction of ro-
botic production cells. In the ideal world, sorting is no longer
needed because the production cell can cut the carcass optimally
based on the biological variation. It assumes that there are suffi-
cient appropriate customer orders received, but overall, it is a big
simplification of the slaughterhouse logistics. A much simpler
design is needed and energy for cooling can even be saved.

As a bonus, it will be possible to introduce complete trace-
ability down to each cut leaving the robotic production cell; a
challenge that remains unsolved today and is currently handled
with batch traceability in most cases.

There Are Still Some Steps to Take

It has been demonstrated that it is possible to make a ro-
botic production cell for a pig slaughterhouse. Technologies are
available and the business case is very attractive. But of course,
there is still a lot of work ahead.

Technically there are three main areas that must be
solved. First of all, it is necessary to develop a very fast
shift of tools may be even on the fly. Robotic production
cells will at least in the beginning need to be fitted into ex-
isting facilities, so a small footprint is essential. Shift of
tools is common in other industries that use robots, but the
challenge is the speed.

Secondly, a sanitation system must be developed. Probably the
most important thing with robotic production cells is that they en-
able production 24/7. The factory can increase its capacity maybe
by 30% without adding any cost of production, and this is where
the real business case for this production setup is hidden. This will
require that the cells can be cleaned in place (CIP). Multiple ro-
botic production cells create a high redundancy in the production
system and, one cell can be cleaned, while the remaining cells are
producing. There already exist CIP systems for robot solutions,
but they have never been tested in slaughterhouses or in this kind
of robotic production cells.

Thirdly, logistics around the robotic production cells must
be in place. Depending on how many operations the cell will
be able to provide, the logistics around the cell will be complex.
It is necessary with a simple conveyor design around the cell
to make logistics as smooth as possible preferably without any
transport boxes. It is easy to underestimate the risk of complex
logistics, and in this case, it is not different.

In the early days of automation, it was popular to state,
that we want so much automation, that we can turn off the
light in the factory, meaning that no people were necessary
for the production. That statement is not relevant anymore,
because robotic production cells still need skilled workers
around them. Actually, the role of the workers will radically
change. Today most of the work is standardized repetitive op-
erations, where each operator is trained in a particular set of
operations. With robotic production cells, the role of the op-
erators is not only to oversee a set of cells but also to be the
product quality expert. The skilled butcher will become very
important, as their skills will be part of the learning input
to the algorithms. If the cell meets a situation, where it does
not know what to do, the skilled operator will teach the ma-
inery, and the cell will have achieved a new learning input.
The job will change from a blue-collar worker to a skilled
technician. Jobs will be much fewer, but they will be better
paid and less strenuous.

How to Get There

How can the slaughterhouses get access to this kind of
technology? As in all aspects of technology development,
someone must be the first mover and probably that is the
companies with the most urgent need. But beware that
there is a dramatic disruptive potential in this technology.
As a robotic production cell is basically a standard indus-
trial platform, it opens for many more technology providers
than the industry has today. Previous solutions were highly
mechanized and integrated tying the slaughterhouse to the
particular technology provider, but with this new produc-
tion paradigm, the field is completely open, and any robot
integrator would potentially be able to enter the arena.
Moreover, the slaughterhouses will claim their rights to the algorithms, which will lower the bargaining power of the technology providers. Good news for the slaughterhouses and good news for new to the business technology providers, who wants to enter the arena.

New technology also means new ways of working. Many slaughterhouses have agreements based on time studies or volumes, and these kinds of agreements will not make any sense with the new technology. As work moves from blue collar to technician type of work, the management approach must change accordingly.

So, the first-mover will not only take the risk but also get ahead of their competition if it is a success and the moment for decision making is coming close.

Self-learning robotic production cells, which are hyperflexible and which can be added with new features, both physically and digitally, represent a disruptive shift in the production paradigm in the meat industry. The circle is closed, and we are back to the cutting table. Maybe, the automotive industry will be inspired again a hundred years after the visit to Swift and Company’s slaughterhouse in Chicago.

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