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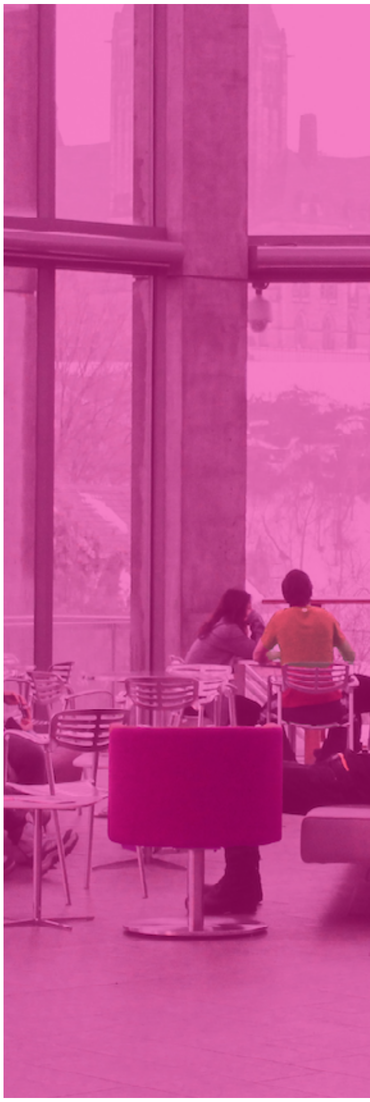
Beefing Up Innovation

Smart Manufacturing and Cutting-Edge Skills for the Meat Processing Industry

Impact paper | June 27, 2025



Future Skills Centre | Centre des Compétences futures

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The Future Skills Centre was founded by a consortium whose members are Toronto Metropolitan University, Blueprint, and The Conference Board of Canada.

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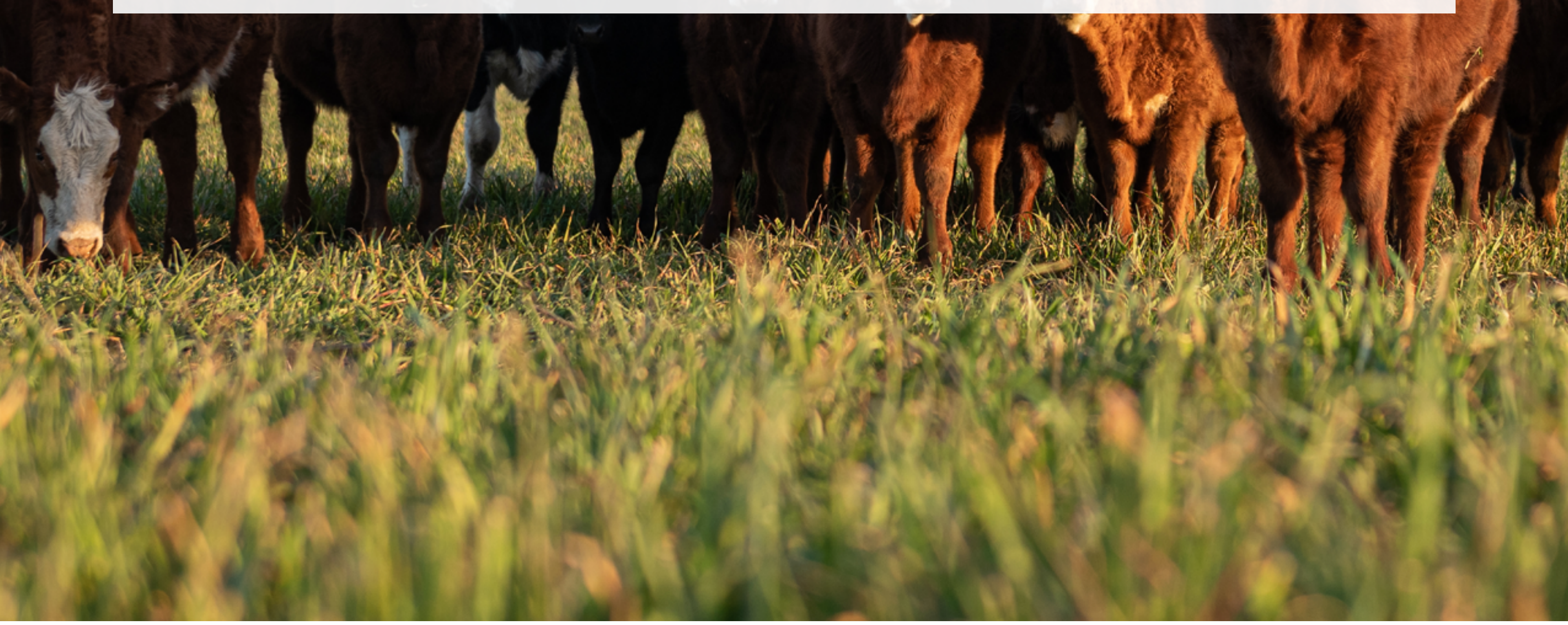
Contents

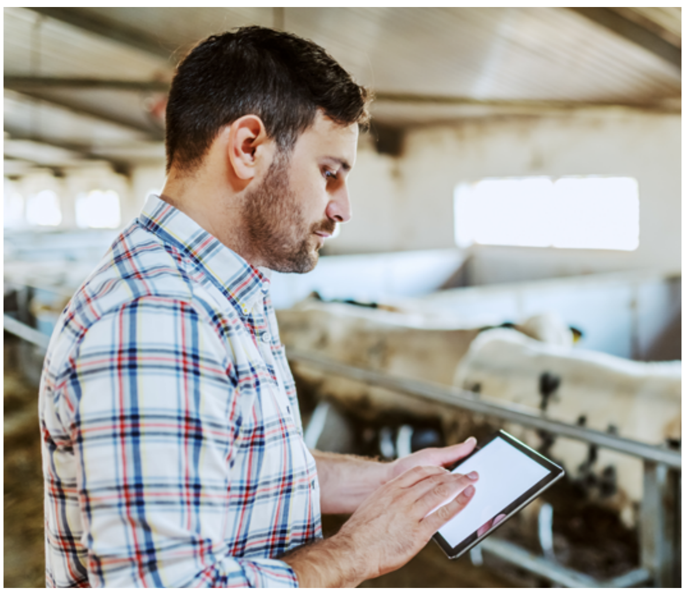
Key findings

- Smart manufacturing in the meat processing industry increases the demand for advanced technical and digital skills, such as robotic operation, control, and maintenance, along with higher levels of education and training including college diplomas and other formal certifications.
- Almost half of unit operations in the primary processing of beef can be automated to some degree, with robots that are at a technology readiness level of 4 and above.
- Only a handful of unit operations in the secondary processing of beef can be robotized. In secondary beef processing, worker skills such as touch sensing, hand–eye coordination, visual perception, decision-making, and dexterity for gripping and manipulating carcasses remain critical, as robots have yet to match the proficiency of humans in these areas.
- By replacing the physical demands, knife skills, and knowledge of animal anatomy with robots in certain operations, smart manufacturing can expand the scope of individuals who can work in the meat processing industry. As such, it creates opportunities for a more diverse workforce.
- Smart manufacturing can transform the safety and working environment of individuals employed in primary beef processing. This is especially true for fully automated, robotized unit operations.
- Semi-automated unit operations in primary or secondary processing can improve the safety of workers, but their working environment is likely to remain unchanged.
- To enable the adoption of smart manufacturing, meat processors can upskill their current workforce while pursuing longer-term strategies to attract workers with robotics and digital skills from outside their industry.
- Demonstrating the benefits of fully automated robotic operations that improve worker safety is key to re-shaping the perception of the industry as a challenging working environment. It is also important for engaging the next generation of workers.
- As legislation to protect consumers against greenwashing intensifies, smart manufacturing can add credibility to sustainability claims, given the richness of data it provides. Meat processors can leverage this data to strengthen sustainability performance and enhance the value of sustainable meat products.



Embracing innovation: The meat of the matter

Despite being an economic powerhouse, Canada's food manufacturing industry, including meat processing, is one of the least innovative in the manufacturing sector.[1] This innovation lag has come at a considerable cost.



The prevalence of low-skilled workers, low wages, and the challenging working conditions in meat processing plants emanate, in part, from this innovation inertia. That said, the recent adoption of robotics, automation, and digital technologies by leading meat processors could bolster innovation and competitiveness, while transforming the skills profile of the industry.

Food manufacturing is Canada's largest manufacturing industry by employment, and the second largest by GDP. It accounts for 14 per cent of manufacturing GDP and 16 per cent of manufacturing jobs in Canada. And the meat processing industry anchors the economic might of food manufacturing. Over a quarter of all jobs and GDP in food manufacturing is due to meat processing.[2] Canadian beef and pork production accounted for $5 billion and $4.7 billion in exports in 2023, respectively.[3] These two meat products had a combined trade surplus of $6.3 billion in the same year.[4]

Labour pains

Canada's meat processing industry is facing acute labour pains. More than half of meat processors cannot find the number of workers or experience levels needed.[5] Meat processing has challenging working conditions, and the safety and well-being of workers is a point of concern for investors and other stakeholders.[6]

1 Statistics Canada, "Use of advanced or emerging technologies."
2 Statistics of Canada, "Gross domestic product (GDP) at basic prices"; and Statistics Canada, "Labour statistics consistent with the System of National Accounts (SNA)."
3 Agriculture and Agri-Food Canada, "Red meat trade reports."
4 Agriculture and Agri-Food Canada.
5 Food Processing Skills Canada, "Canadian Meat and Poultry LMI – Executive Summary."
6 FAIRR, "Meat Companies' Inaction on Working Conditions Contributing to Labour Shortages."

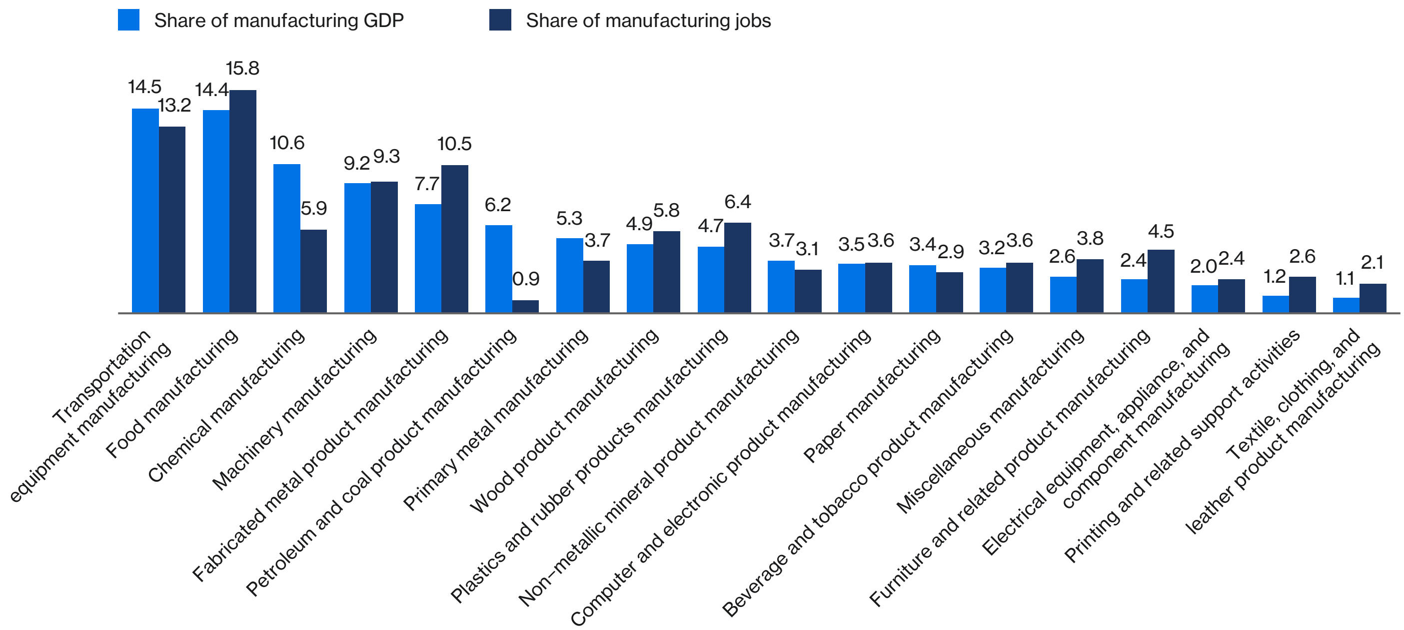
For instance, in the U.S., animal slaughtering and processing results in approximately four severe injuries per week—causing hospitalizations, amputations, or loss of vision.[7] Closer to home in Alberta, where 70 per cent of beef processing happens in Canada,[8] workers in the meat processing industry had the highest claims of joint and muscular inflammation illnesses, as well as musculoskeletal injuries.[9]

Compensation has also declined. Wages that were 8 to 12 per cent higher than the Canadian manufacturing sector average in the 1980s dropped to 15 per cent below average in 2022.[10]

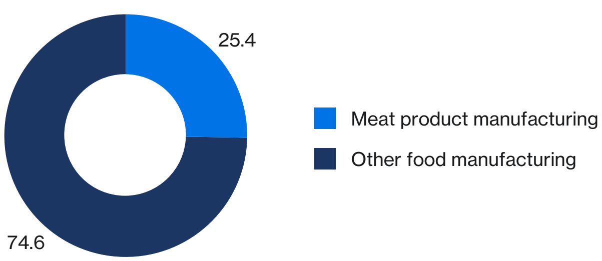
Much is at stake. Meat processing accounts for about 25 per cent of Canadian food manufacturing jobs and GDP. (See Chart 1.) Meat processors are making strides to turn the corner on these labour-related challenges by embracing smart manufacturing innovation.

Chart 1

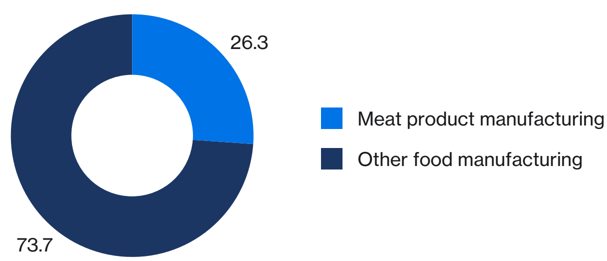
Meat processing accounts for about 25 per cent of jobs and GDP in Canadian food manufacturing
(per cent)



Share of food manufacturing GDP



Share of food manufacturing jobs



Sources: Statistics Canada; The Conference Board of Canada.

7 OSHA, *Severe Injury Report*.
8 This is based on federally inspected beef processing plants.
9 Government of Alberta, *Workplace injury, illness and fatality statistics*.
10 MacLachlan, *Kill and chill*; and Innovation, Science and Economic Development Canada, “Salaries and wages.”

Going smart

Smart manufacturing uses an automated, digital, and sustainability-conscious business model to increase the efficiency of traditional manufacturing approaches, resulting in more agile and productive industries.[11] These technologies streamline operations while ensuring high-quality products and operational resiliency.

Leading meat processors such as Cargill and JBS Foods are adopting smart manufacturing.[12] This includes the use of robotics, automation, and digital technologies in their processing plants. It's worth noting that other low-wage, low-skill industries, such as textile, fabricated metal, and wood product manufacturing, are also adopting smart manufacturing technologies.[13]

The potential gains in productivity, operational resilience, and sustainability are compelling for meat processors. Some studies show that the benefits of smart manufacturing technologies can outweigh their costs. For instance, an automated beef carcass yield estimation system can have a benefit–cost ratio of 1.72.[14]

The impact of smart manufacturing goes beyond the operations and affects the skills, safety, and the operational environment of workers. To illuminate these impacts, we compare the unit operations and skills in meat processing, for both smart and conventional plants.

To conduct this comparison, we've developed a skills framework for smart and conventional meat processing plants. This allows us to address two pressing questions:

- What is the impact of smart manufacturing on the skills required in meat processing plants?
- How will the human–robot interactions in smart manufacturing improve safety and the working environment?

11 Thompson, "What is smart manufacturing, and how is it changing the industry?"

12 For instance, Cargill has invested $US100 million toward its Factory of the Future systems, which combines advanced automation and data systems. Additionally, JBS Foods has partnered with Scott technologies for a $71-million project focused on automating warehouse operations. Tyson Foods has announced planned investments of $US1.3 billion in automating its plants.

13 Innovation, Science and Economic Development Canada, "Summary – Canadian Industry Statistics"; and Employment and Social Development Canada, "View Unit Group."

14 Wakholi and others, "Economic Analysis of an Image-Based Beef Carcass Yield Estimation System in Korea."

In focus: Beef processing

Beef is the highest value meat product in Canada, and Canada is one of the top 10 beef producing and beef exporting countries, globally.[15]

Large firms rule

Beef processing in Canada is highly concentrated and dominated by large firms. In 1988, Canada had 119 federally inspected beef processing plants.[16] From 2015 to 2022, while the number of federally inspected beef plants in Canada decreased by 5 per cent, the beef slaughtered increased by 31 per cent.[17] By 2024, there were only 17 beef processing plants in the country.[18] Four companies accounted for 95 per cent of slaughtered Canadian cattle in 2024—this has dropped slightly from 98 per cent in 2015.

Diversification is key

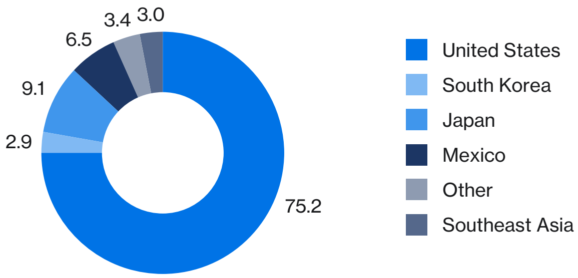
Across many export sectors, Canada is heavily reliant on the U.S. market. The beef industry is no different. In 2023, over 75 per cent of Canadian beef exports were destined for the United States. (See Chart 2.)

As Canada's beef industry looks to diversify its exports outside of the U.S., it is critical to identify high-impact growth opportunities in non-U.S. markets. Chart 2 highlights two important facts. First, the second largest share of beef is exported to Asian markets, especially Japan and South Korea, which together account for 12 per cent of exports. Canada can expand its export share to this high-growth region. Second, only a small proportion of Canadian exports go to Europe largely due to differences in standards and regulations between the two regions, such as the EU ban on carcasses washed with peroxyacetic acid.[19] While the 2017 Comprehensive Economic and Trade Agreement with the EU increased access to the European market, the Canadian beef processing industry has yet to make meaningful inroads.

Chart 2

75 per cent of Canadian beef exports go to the United States

(per cent)



Sources: Canadian Beef; The Conference Board of Canada.

15 Canadian Beef, *Canada's Beef Industry Fast Facts*.

16 National Farmers Union, *Meat packing concentration makes Canada's food system vulnerable*.

17 Agriculture and Agri-Food Canada, "Distribution of slaughtering activities."

18 Agriculture and Agri-Food Canada.

19 Ghazalian, "Enhancing Canada's Beef Exports and Competitiveness in the Global Market."

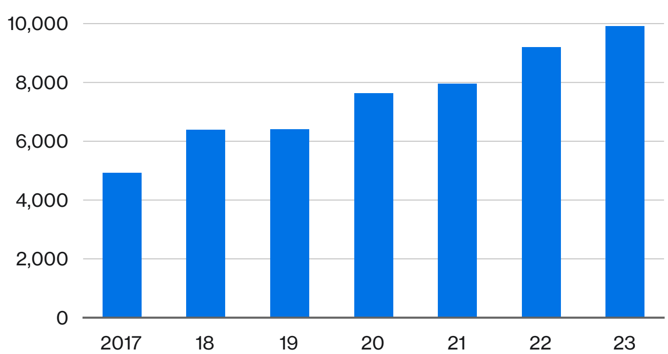
Strategic vulnerabilities: Immigration

Immigrants are disproportionately represented in Canada's meat manufacturing industry. While 23 per cent of Canadians were born outside the country in 2021, immigrants made up 57 per cent of the workforce in the meat manufacturing industry.[20] The number of temporary foreign workers in the industry also doubled from 2017 to 2023. (See Chart 3.) Following the boom in immigration in 2021 and 2022, the immigration consensus in Canada has fractured. As such, the ongoing reliance on temporary foreign workers presents a vulnerability. This concern is heightened by Canada's March 2024 plans to reduce the proportion of temporary residents to 5 per cent of the total population within the next three years.[21]

Chart 3

The number of temporary foreign workers in meat processing doubled between 2017 and 2023

(number of temporary foreign workers)



Note: The temporary foreign worker data for meat processing is based on workers in the meat product manufacturing industry – North American Industry Classification System (NAICS) 3116. This industry group consists of firms primarily engaged in manufacturing meat products.
Sources: Statistics Canada; The Conference Board of Canada.

Smart processing plants

Exhibit 1 shows the operational configuration for a smart beef processing plant. Smart manufacturing technologies for meat processing are at different levels of technological maturity depending on their application. We focus on the state-of-the-art technologies that are commercially available or in development. The minimum threshold for inclusion of smart manufacturing technologies is a technology readiness level (TRL) of four. (See Methodology.)

Aside from an extensive review of literature, our inclusion of smart manufacturing technologies that represent the state-of-the-art was also informed by 12 expert opinion interviews.

The working environment

The working environment in conventional beef processing facilities is challenging. Workers are exposed to the viscera, pungent odours, sounds of nervous animals, or heavy machinery for work shifts that are typically eight hours in length. Additionally, the physical environment where workers are situated varies from being warm and humid in the primary processing slaughtering areas, to cold and damp in the secondary processing areas where room temperatures must be 10°C or lower.[22] In addition, the work can be physically taxing.

Smart manufacturing and the use of robotics can transform the working environment of workers. The use of robotics in the unit operations for meat processing reduces or eliminates these challenging working conditions and consequent safety risks.

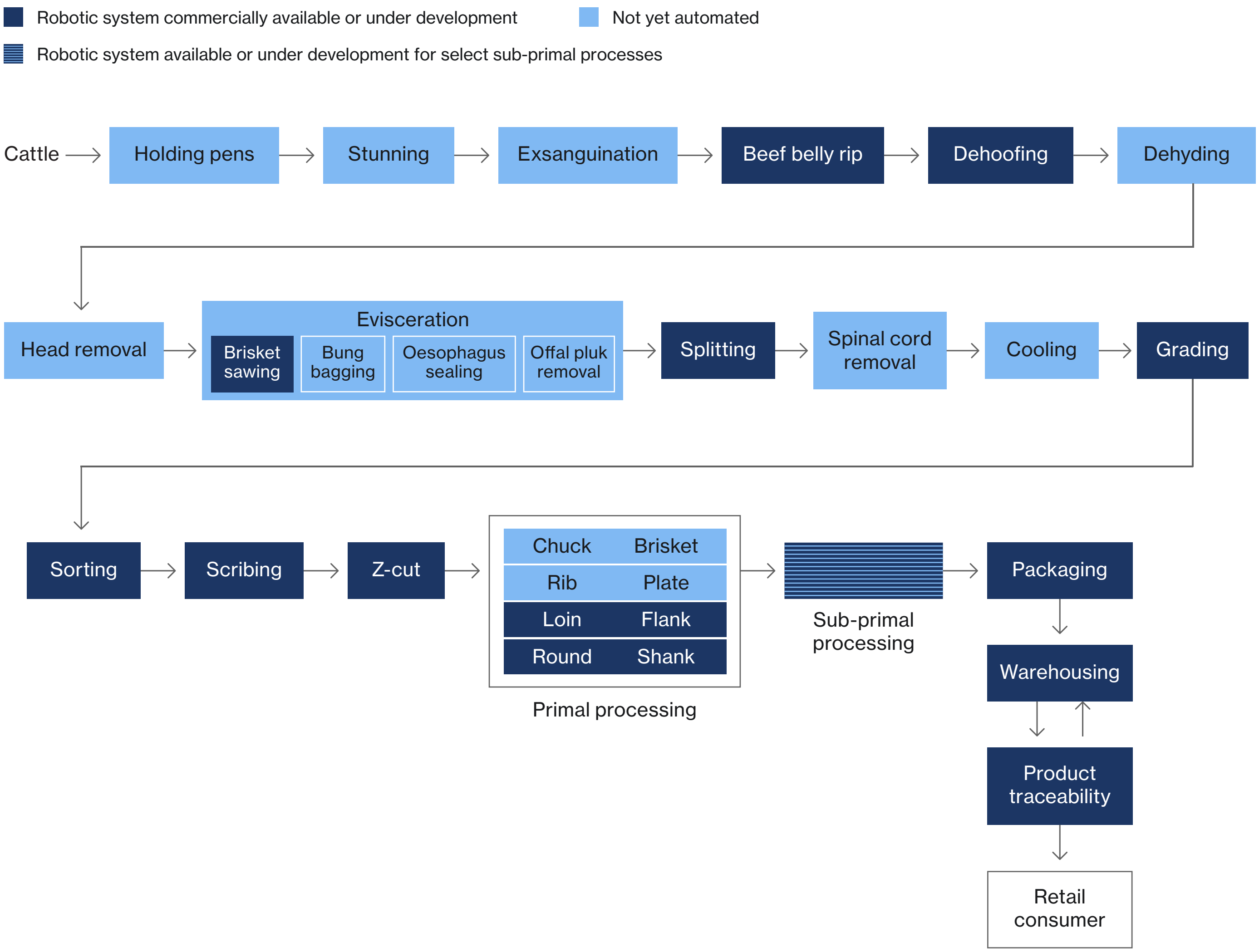
To understand these potential impacts on the working environment and safety of workers, we highlight the four different categories of human robot interaction (HRI) below. These HRI categories are illustrated in Exhibit 2.

20 Immigration, Refugees and Citizenship Canada, "An Immigration System for Canada's Future"; and Statistics Canada, "Class of Worker."

21 Immigration, Refugees and Citizenship Canada, "2025–2027 Immigration Levels Plan."

22 Government of Ontario, Food Safety and Quality Act.

Exhibit 1
A smart beef processing plant



Note: Primary processing in beef plants begins at the holding pens and ends during the Z-cut operation. Secondary processing includes all unit operations after the Z-cut to sub-primal processing.
Source: The Conference Board of Canada.

Human–robot interaction

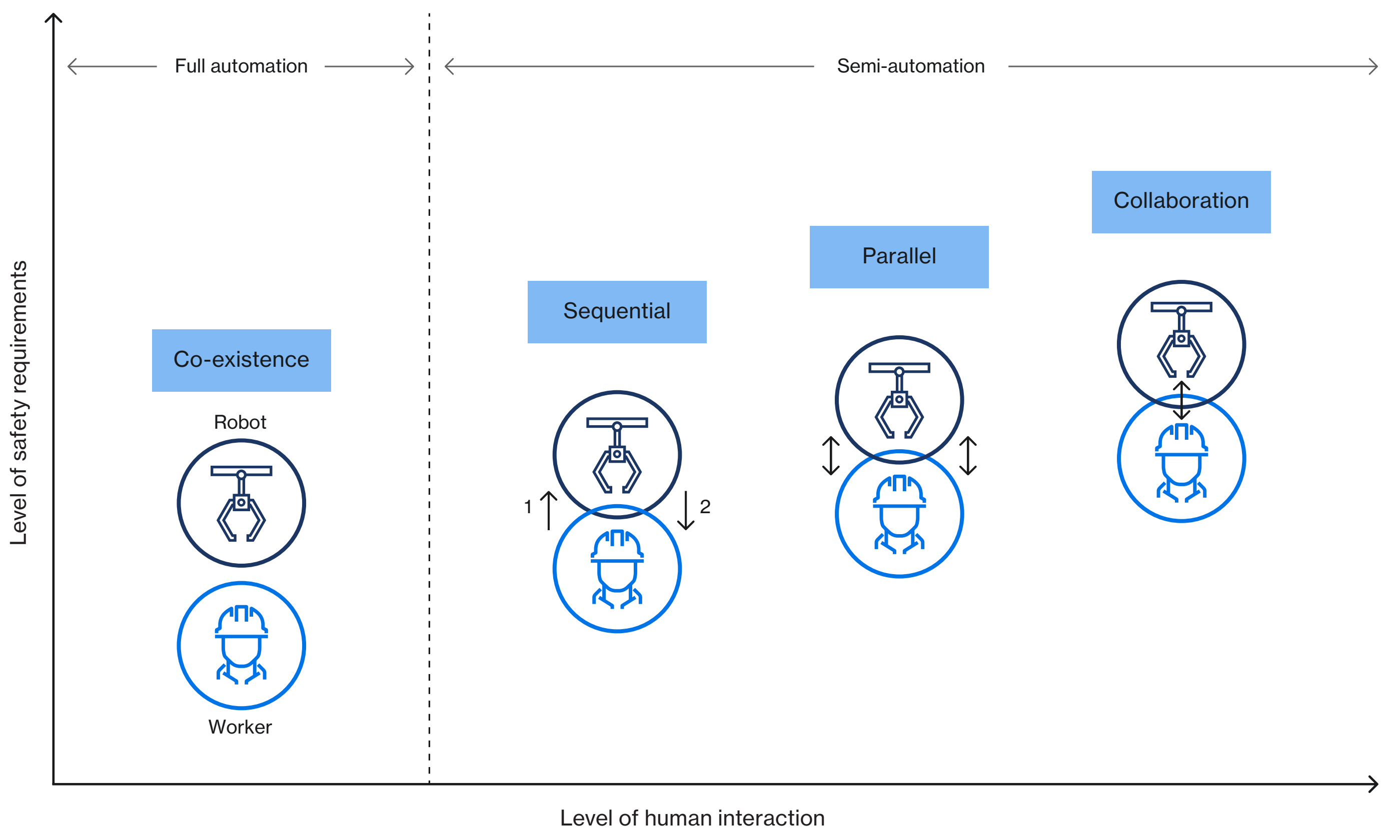
We divided the smart unit operations in beef processing plants into various levels of automation based on the following HRI categorization:[23]

1. **Co-existence:** The human and robot do not share the same workspace and work separately from each other.
2. **Sequential:** The human and robot share the same workspace and perform tasks in succession to one another.
3. **Parallel:** The human and the robot share the same workspace and perform tasks simultaneously.
4. **Collaborative:** Real-time manipulation of the robot by the human operator (e.g., wearable robots, co-bots).

Co-existence refers to those unit operations that are fully automated, while sequential, parallel, and collaborative HRIs represent semi-automated operations. As shown in Exhibit 2, the level of automation decreases from co-existence onwards. A collaborative HRI represents the lowest level of automation.

It is important to note that the use of robots also introduces safety considerations of their own. As illustrated in Exhibit 2, the higher the level of human–robot interaction, the greater the safety measures required. That said, the potential for robots to improve the safety and working environment of workers in meat processing remains unchanged. This is discussed further in the Safety first section.

Exhibit 2
Co-existence is the safest and most automated HRI classification



Source: The Conference Board of Canada.

23 Romanov and others, "Towards human–robot collaboration in meat processing."

Primary processing

Primary processing refers to the initial stages in beef production, which include slaughter, cutting, and inspecting beef to prepare it for further processing into consumable products. Primary processing in smart plants involves the use of automation in the form of robots for several unit operations. This contrasts with conventional plants where these processes are carried out manually by humans. In smart plants, primary processing begins at the holding pens and ends during the Z-cut operation.

Workers in meat processing plants are often involved in both primary and secondary processing. This includes occupations such as industrial butchers and meat cutters.

Degrees of automation

The extent of automation varies widely in primary beef processing. Several unit operations in primary processing are fully automated (i.e., workers are in co-existence with robots). This includes dehoofing, splitting, grading, and scribing. (See Table 1.) These automated unit operations displace many of the workers and their associated skills required to perform these tasks in conventional beef processing facilities. Other unit operations are semi-automated. For instance, four operations in primary processing are sequential according to the HRI categorisation. The impact of these semi-automated processes is less disruptive on the skills of workers.

To account for the specific impacts of smart manufacturing on the worker skills in primary processing, we use two-unit operations as indicative examples, scribing and Z-cut. Scribing is fully automated and Z-cut is semi-automated. These unit operations reveal the new skills required, the conventional skills that remain important, and those conventional skills that are rendered obsolete. This evolution of skills is summarized in tables 2 and 3.

Robotic scribing: Impact on skills

In conventional processing plants, manual scribing[24] involves two workers using an electrically powered heavy circular saw to perform two vertical cuts 160 mm apart on each beef carcass. This task is physically demanding and repetitive. It is also considered by some to be one of the most dangerous tasks in a meat processing facility.[25] Workers rely on their vision and saw-handling capability.

The skills required to manually perform this operation include judgment and decision-making, identification of scribe cut location, and executing accurate cuts. Performing this operation eight hours a day can lead to physical strain and uneven cuts resulting from worker fatigue, inadvertently reducing carcass yield quality.

Robotic scribing is a fully automated operation that has a disruptive impact on worker skills. A scribing robot can scribe the carcass automatically thereby shifting the human operator's skills needs toward robot control and maintenance. (See Table 2.) The adoption of smart scribing displaces a variety of skills across four categories. Additional details regarding the skills categories used in this impact paper are outlined in Methodology.

24 Scribing is an activity where reference cuts are placed on a beef side to help improve yield quality in downstream beef processing. The scribing unit operation is highlighted in this analysis as scribing robots have attained a co-existence HRI commercially, and are deployed in the Kilcoy plant in Australia.

25 Australian Meat Processor Corporation, "Beef scribing program – optimizing each carcase."

Table 1
Smart unit operations and their corresponding human robot interaction

Unit operation	Description	Human–robot interaction (HRI)
Primary processing		
Holding pens	Upon arrival, cattle are held in pens where they are cleaned prior to being moved into the slaughter facility.	Not applicable – remains a manual operation
Stunning	A captive bolt stunning device is used to make the animal unconscious.	Not applicable – remains a manual operation
Exsanguination	A knife is used to sever blood vessels in the neck region for blood drainage.	Not applicable – remains a manual operation
Beef belly rip	A skin-deep cut is made along the midline of the carcass for dehiding (i.e., removing its hide). The beef belly rip robot can conduct this using an infrared laser distance sensor to profile the carcass and control software to operate the robot.	Sequential
Dehoofing	This involves cutting the hooves off the cattle. This is automated using robots with integrated sensing profiles to stabilize and accurately cut the hooves.	Co-existence
Evisceration	Evisceration removes all the viscera form the carcass. This includes brisket sawing, bung bagging, esophagus sealing, and offal removal. The brisket sawing robot makes sternal cuts using an automated saw, sensing system, and software.	Sequential for brisket sawing
Splitting	The carcass is split into two halves along the backbone for further processing and inspection. The carcass can be split using an ultrasound-guided automated carcass splitter.	Co-existence
Spinal cord removal	Removing the spinal cord as per safety guidelines and requirements.	Not applicable – remains a manual operation
Grading	Canadian beef is graded by the Canadian Beef Grading Agency. The carcasses are graded according to a quality grade and a yield grade. The quality grade measures several characteristics, such as the maturity, age, sex, fat, colour, texture, and marbling – whereas the yield grade measures yield for retail sale. An automated beef classification system can conduct grading using 3D imaging technology to capture size, shape, and fat content. AI algorithms then predict quality and grade.	Co-existence
Sorting	The carcasses are sorted based on weight, class, grade, and customer code in the chill rooms. An automated chill room accomplishes this using overhead rails for transporting carcasses and intelligent software to automatically sort the carcasses based on the previously described characteristics.	Sequential
Scribing	This involves making a series of vertical and horizontal scribes along the ribs to demarcate cuts and improve yields for further processing.	Co-existence
Z-cut	This process cuts along the 13th rib and spinal column to separate the front quarter from the hind quarter.	Sequential
Secondary processing		
Primal processing	After the two halves are split into front and hind quarters, they are processed into their respective primal sections. These primals include chuck, brisket, rib, plate, loin, flank, round, and shank. The beef loin drop is automated with vision control systems during which the loin is separated from the round.	Co-existence for beef loin drop
Sub-primal processing	The primals are broken down into various cuts of meats, such as steaks, roasts, and ground beef. Several stages within sub-primal processing can be automated such as chine removal, striploin fat trimmer, and shank processing.	Sequential for chine removal, striploin fat trimmer, and shank processing
Packaging and distribution		
Packaging	Meat products are packaged using a range of materials, including bags, trays and vacuum-sealed pouches. This is accomplished using automation technology that uses vacuum technology, grippers, and paddle lifts to package different product shapes and sizes.	Co-existence
Warehousing	This involves storing meat products in controlled temperatures to maintain freshness (e.g., refrigeration and freezing). They are then distributed to grocery retail and food service establishments as well as other consumers. Automated warehouse systems that use execution software can pick, store, and pelletize the boxes.	Co-existence
Traceability	Traceability at the processing stage allows meat products to be traced back to the group of animals that were processed on a particular day. Some automated cameras in boning rooms can use AI to match primal cuts back to the original carcass.	Sequential

Sources: Kentmaster Australia; Ontario Ministry of Agriculture, Food and Agribusiness; Templer and others; Beker and others; Boyce and others; Meat and Livestock Australia Limited; BC Ministry of Agriculture and Food; Guire and others; Intelligent Robotics; Beef Cattle Research Council; Frontmatec; The BC Cook Articulation Committee; JLS Automation; JBS Foods; Australian Meat Processor Corporation; GS1 Ireland; The Conference Board of Canada.

Table 2
Shifting skills in smart scribing

Displaced	New	Common
General skills • Hand–eye coordination to perform accurate cuts • Handle repetitive tasks • Operate heavy load continuously	**Content skills** • Reading comprehension	**Content skills** • Active listening to surroundings • Speaking clearly and conveying information effectively
System skills • Using judgment to determine scribe locations • Analyzing socio-technical context characterized by humans and manual tools • Evaluating socio-technical system	**System skills** • Determining how a robot-cutting system should work and how changing conditions will affect outcomes • Identifying measures of system performance and actions needed to properly orient the robot	**Process skills** • Active learning through the incorporation of new information • Critical thinking – reasoning to evaluate solutions to problems • Learning strategies – using appropriate training methods when learning or teaching new things • Monitoring and assessing one's own performance, as well as the performance of others
Technical skills • Manually operate a heavy circular saw • Maintain power tool equipment • Tool and equipment selection • Operating and controlling equipment • Monitoring operations to make sure equipment is functioning properly • Testing and inspecting products to evaluate quality • Repairing tools • Troubleshooting to determine the cause of operating errors • Manual identification of the scribe cut location • Performing accurate scribe cuts • Sanitizing conventional equipment	**Technical skills** • Performing routine maintenance on robot • Operating and controlling the robot • Performing minor repairs on the robot • Troubleshooting problems with the robot • Verifying the operation of automated equipment sanitation	**Resource management skills** • Managing the appropriate use of resources, including equipment • Time management
Social skills • Coordinating actions with co-workers • Instructing entry-level employees • Using social skills to persuade colleagues (needed for a two-person job) • Social perceptiveness (needed for a two-person job)	**Complex problem-solving skills** • Identifying and solving novel problems associated with the robot-cutting process	**Not Applicable**

Source: The Conference Board of Canada.

Z-cut robot: Impact on skills

Partially automated processes are more dependent on workers. In conventional plants, manual ribbing requires two workers to physically cut through the ribs of the beef carcass to separate the forequarter from the hind quarter. This process is semi-automated in a smart plant. A Z-cut[26] robot uses computer vision to locate the fifth and 13th ribs, obtain the cut path, and perform the cuts maintaining a constant distance from the spine—transforming a half carcass side into a forequarter and hind quarter.

The Z-cut displaces a variety of skills that were previously required in conventional processing. (See Table 3.) Skills that involve the use of sharp knives and power tools are displaced. Complex problem-solving, judgment, and decision-making skills are examples of the new skills introduced, alongside digital skills related to robot operations and control. As it is semi-automated, the Z-cut robot needs a worker to enter the file cut path from the computer vision system to the robot cutting tool for each side of the carcass.[27] Thus, the human operator is more involved in robot operations and control compared with a fully automated system, such as scribing.

Changing landscape of new skills

Smart manufacturing is poised to alter the skills landscape for workers in processing plants considerably. The introduction of these innovative technologies, such as smart scribing and Z-cut machines, brings forth a new era of automation, where skills like robotic operation and control take precedence. These skills necessitate higher levels of education and training, including college diplomas and other formal certifications. By replacing the physical demand of operations with robots, smart manufacturing also expands the scope of individuals who can perform these operations, creating opportunities for a more diverse workforce.

> "I don't have to go and do physical labour if I can just press the button, and the robot does it for me. It can also give opportunities to persons with disability who can press the button, but not necessarily lift the carcass, and do anything physical."
>
> **Interview participant**

Secondary processing

Secondary processing involves transforming beef quarters into their respective primal and sub-primal cuts through activities such as cutting, deboning, portioning, and trimming. This process ultimately turns them into consumable products. Exhibit 1 shows secondary processing as encompassing all operations following Z-cut up to sub-primal processing.

Robots lack dexterity

The adoption of smart manufacturing in secondary beef processing is currently limited. While post-processing stages such as packaging and traceability are automated, the overall automation in secondary beef processing remains confined to a handful of operations. In primary processing, there are eight automated unit operations, with half being fully automated. In contrast, secondary processing features only four automated operations, with just one being fully automated. (See Table 1.)

In secondary processing, human skills such as touch sensing, hand–eye coordination, visual perception, decision-making, and dexterity for gripping and manipulating carcasses remain critical, as robots have yet to match the proficiency of humans in these areas.[28] Accurate cuts are vital for producing high-quality meat that meets consumer demand, while effective deboning minimizes waste and maximizes yield. Meat cutters possess a deep understanding of animal anatomy and excellent knife skills to perform these tasks.

As such, few smart secondary processing operations exist. Those that do mainly perform similar tasks to primary processing, rather than completely deboning a product. Examples include beef loin drop and chine removal operations.

26 Z-cut transforms a half carcass into a forequarter and a hind quarter using a robot. It replaces the manual ribbing between the 12th and 13th rib cross section and the 5th and 6th rib cross section in a conventional plant.

27 Guire and others, "Robotic Cell for Beef Carcass Primal Cutting."

28 Khodabandehloo, "Achieving robotic meat cutting."

Table 3
Skills in smart Z-cut

Displaced	New	Common
General skills • Hand–eye coordination to perform accurate cuts on carcass • Operating sharp knife continuously • Handle repetitive ribbing task	**General skills** • Hand–eye coordination to ensure accurate cut paths	**General skills** • Visual perception
Social skills • Coordination – adjusting actions in relation to a human colleague • Instructing entry-level employees	**Social skills** • Coordinating action with robot partner • Training robot partner to conduct Z-cut	**Resource management skills** • Managing the appropriate use of resources, including equipment • Time management
System skills • Judgment and decision-making skills related to manual ribbing system • Analyzing how the manual ribbing system should work and how changes will affect outcomes • Identifying measures of system performance in relation to manual ribbing	**System skills** • Judgment and decision-making skills related to verification of robotic Z-cut path • Determining how robotic Z-cut system should work and how changes will affect outcomes • Identifying measures of robot system performance and actions needed to correct	**Process skills** • Active learning through the incorporation of new information • Critical thinking – reasoning to evaluate solutions to problems • Learning strategies using appropriate training methods when learning or teaching new things • Monitoring and assessing one's own performance, as well as the performance of others
Technical skills • Manually using a sharp knife to make ribbing cut • Maintaining power tool equipment • Determining and selecting needed tools • Controlling the operation of the manual ribbing system • Monitoring indicators to ensure cutting tools are working properly • Quality control – testing and inspecting products for quality • Repairing cutting tools • Troubleshooting causes of operating errors and deciding what to do • Manually identifying the rib location • Performing accurate cuts • Sanitizing conventional equipment • Knife-sharpening skills	**Technical skills** • Performing routine maintenance on the robot • Operating and controlling the robot • Monitoring indicators to ensure the robot is working properly • Quality control – inspecting products to verify robot cut quality • Performing minor repairs on the robot • Troubleshooting operating errors and determining solutions • Manually loading the cut path on the robot tool • Verifying the operation of automated equipment sanitation • Modifying the Z-cut path as required	**Not Applicable**
Not Applicable	**Content skills** • Reading comprehension	**Content skills** • Active listening to surroundings • Speaking clearly and conveying information effectively
Not Applicable	**Complex problem-solving skills** • Identifying and solving novel problems associated with the human-robot Z-cut process	**Not Applicable**

Source: The Conference Board of Canada.

Fully automated primal processing: Robotic loin drop

In conventional plants, a beef loin drop involves a worker using a band saw to manually separate the round and shank from the loin and flank. The skills needed to manually perform this task include judgment and decision-making, identification of cut location, and executing accurate cuts while keeping up with the line speed of the processing facility. Uneven cuts can lead to yield loss and product waste.

Robotic secondary processing systems can efficiently separate large primals. For instance, a fully automated beef loin drop robot uses computer vision to precisely identify the cut path location. The robot then controls a band saw to automatically separate the round and shank from the loin and flank.[29]

Prior to this, the robot undergoes a training and testing phase, during which human workers with butchery skills provide input to develop the robot's intelligence. Once fully trained, the robot will be able to perform the task independently, requiring little to no human involvement. Such fully automated operations are currently limited to primal operations and are not yet available for deboning and sub-primal operations.

"The interface for programming the robot so that it develops its own controlling intelligence and improves constantly would be an important contribution from the workers in the factory."
Interview participant

Semi-automated primal processing: Robotic chine removal

Conventional chine removal requires a worker to physically hold the striploin with the chine bone facing the cutting tool, and manually moving the striploin through a band saw to separate it from the chine bone. Often, a second cut is made to refine the first and ensure that the bones are fully separated. Since the fat depth in a striploin varies across the product, the meat cutter must rely on guesswork to create an even fat cap when performing this task manually.[30]

The robotic chine removal has a sequential HRI and requires the operator to load the striploin onto a robot conveyor with the chine bone facing the band saw. A system of 3D scanners profiles the striploin and the bandsaw automatically adjusts to cut the chine bone as the striploin moves through the conveyor.[31] The transition in skills shifts from bandsaw mastery to robotic operations and control. Skills that once required intense hand–eye coordination to manually guide the striploin through a bandsaw are now replaced with new skills that involve using hand–eye coordination to precisely position the striploin on the robot conveyor tool, while ensuring the robot line system is operating smoothly and efficiently.

29 Frontmatec, *Increase Your Yield With a More Accurate Cut.*
30 Meat and Livestock Australia Limited, *LEAP for Beef Sub project 1.*
31 Midwest Machine LLC, "Automated Smart Rib Saw."

Safety first: Elevating the well-being of workers

Transformative opportunities

Fully automated operations in primary beef processing can transform working environments. For instance, in operations with a co-existence HRI, where robots and humans do not share the same workspace, workers can control and supervise robots from a location beyond the processing plant, which avoids its challenging environment. What is more, workers would not need to handle heavy tools or dangerous saws as in the case of conventional scribing. As such, all things being equal, injury rates and musculoskeletal illnesses are expected to reduce substantially. Workers in smart unit operations, including dehoofing, splitting, grading, and scribing, could see a step change in the safety and quality of their working environment.

Caveats for full automation in secondary processing

Although a few automated secondary processing unit operations exist, they represent only a small sub-set of the operations performed on a carcass. For example, the smart beef loin drop separates the round and shank from the loin and flank; however, further processing such as deboning, portioning, and trimming is required to get retail meat cuts. Therefore, while operators can control automated systems like the smart beef loin drop from a comfortable temperature-controlled room, the need for further processing of the meat cuts exposes them to the working environment in conventional facilities.

In essence, compared with secondary processing, the working environment improvements will be more pronounced in primary processing, where the entire unit operation can be fully automated.

Semi-automation elevates safety in unchanged conditions

Semi-automated unit operations in primary processing can raise the standards of worker safety. For instance, robots used for beef belly ripping, brisket sawing, and Z-cutting are semi-automated with a sequential HRI. These robots perform repetitive tasks such as operating heavy power tools on the carcass, thereby reducing muscular strain, operator fatigue, and workplace injuries. However, despite the robotic assistance, the working environment in sequential HRIs can still be harsh.[32] As the operator and robot share the same workspace, depending on the position of the operator in the processing facility, the working conditions could remain unchanged.

In secondary processing, semi-automated unit operations also offer improvements in worker safety compared with their non-automated counterparts. For example, robots for the chine removal, striploin fat trimmer, and shank processing are semi-automated. These robots perform the physical task of cutting and portioning but still require operators to work near the device to load and align the meat product for precise processing by the robots. As a result, the risk of severe lacerations, musculoskeletal conditions, and other injuries are expected to decline.

It is important to note that operators may be required to run multiple robots. This can reduce the repetitive nature of the work, creating more engaged and stimulated workers. In essence, while working conditions remain the same, the level of physical exertion by workers is reduced and replaced with tasks that require more advanced skills, such as robot control and maintenance, as well as problem-solving.

32 Templer and others, “Innovative Robotic Applications for Beef Processing.”

Leaning into change: Recommendations

The meat processing industry is making a gradual pivot to smart manufacturing. This is, in part, driven by the industry's challenges with attracting and retaining workers, which reduces profitability and the reliability of production. The business model for conventional processing plants is dependent on the supply of low-skilled and low-wage workers who are often sourced from an immigrant labour pool.

We offer four recommendations to foster competitiveness and sustainability in the industry, while mitigating these labour-related challenges.

Showcase opportunities with transformative potential for workers

To adopt smart manufacturing, meat processors should prioritize the upskilling of their existing workforce in the short to medium term. These efforts should be complemented by longer-term strategies to attract higher-skilled talent from outside the industry. On this latter point, processors need to work with skills and capacity development entities to showcase the potential for transformative changes in the working environment and worker safety areas.

Fully automated unit operations that have a co-existence HRI have the most potential to change working conditions and safety. But seeing is believing. Canadian processors will need to collaborate in providing a demonstration of these robotized unit operations for prospective workers. Changing the perception of the industry's working environment begins with elevating the safety and experience of workers.

Increase product value with sustainability

Smart manufacturing will demand new skills from workers that will in turn elevate worker education and certification requirements. This can be expected to also raise wages.

To manage a rise in wages, processors should use the sustainability attributes of meat produced using smart manufacturing to communicate a new value proposition with consumers. Sustainability and environmental claims for goods and services are under intensified scrutiny by regulators for greenwashing (when companies claim their product is more sustainable than it really is). Smart manufacturing is poised to provide a data-rich and thorough evidence base for sustainable meat. Smart manufacturing can address social and environmental issues of the highest priority in the meat value chain.[33] This can complement and extend the value of existing sustainability certifications for meat products in Canada (e.g., Canadian Roundtable for Sustainable Beef).

Processors can capture a new sustainability premium with consumers that elevates the price point of meat products. This is not theoretical. Meat products with labels such as "organic" or "raised without antibiotics" have secured a higher price point relative to conventional alternatives.[34] A recent study showed that grass-fed beef had premiums of 150 per cent to 193 per cent compared with conventional grain-fed beef for premium cuts such as sirloin, tenderloin, etc.[35]

33 An upcoming Conference Board of Canada publication examines the high-priority sustainability issues in the meat value chain and the ability of smart manufacturing to address them.

34 Page, "Chicken products labeled 'raised without antibiotics' and 'organic' command higher prices."

35 Wang, Isengildina-Massa, and Stewart, "US grass-fed beef premiums."

Engage Canada's AI and robotics innovation ecosystem

The use of AI-enabled robotics will alter the fundamentals of a comparative advantage in the meat processing industry. Rather than a reliance on the experiential knowledge and skills of workers as part of their competitive advantage, processors will become increasingly dependent on intelligent, self-learning algorithms for robotics.[36] Many of the robotic applications for secondary processing are still in their infancy. Radical smart manufacturing innovations such as cell-based meat processing are further into the future and will require AI.

Canada is a leading jurisdiction in AI innovation. It is ranked first or second among G7 countries in AI talent concentration, research publications, and patents.[37] Governments can work to deepen the innovation networks between Canada's AI innovation actors (e.g., Alberta Machine Intelligence Institute, Canadian robotic technology companies[38]) and Canada's meat processors. Institutional vehicles such as the Canadian Agri-Food Automation and Intelligence Network Ltd. can be strengthened by governments with long-term funding support to achieve this.

Canada's Achilles heel has been the commercialization of innovation. It is in the bottom tier of advanced economies in terms of the adoption of robotics in manufacturing. As such, the agenda of the innovation network must be pragmatic and value-driven, with a clear connection to the profitability of processors among other pain points.

Develop smart manufacturing solutions for medium-sized processors

Canada's medium-sized firms are an opportunity to be included in the drive for innovation and increased productivity in meat processing. Twenty per cent of meat processors are small firms with fewer than five employees, and 45 per cent have 10 or fewer workers.[39] These firms do not have the capital and production scale required to justify the adoption of smart manufacturing. Medium-sized firms with employees ranging from 100 to 499 are better positioned. They account for 16 per cent of meat processors.

Governments should ensure that Canada's innovation agenda is inclusive of this cohort of medium-sized firms. There is a spectrum of robotics and automation technologies that can be "right-sized" for their needs and scale. However, robotics and AI companies need engagement platforms that provide consistent access to a critical mass of medium-sized processors. This critical mass is important in deploying robotics and automation at a scale that is commercially attractive. Governments in collaboration with innovation enablers are well positioned to play this "integrator" role.

36 Hinrichsen and others, "We need to rethink production technology for meat packers."

37 Deloitte, "Impact and opportunities: Canada's AI ecosystem."

38 Canada has a vibrant robotic industry with Canadian start-up firms like Clearpath Robotics being acquired by Rockwell Automation, a large multinational smart manufacturing company.

39 Innovation, Science and Economic Development Canada, "Salaries and wages"; and Food Processing Skills Canada, "Canadian Meat and Poultry LMI."

Appendix A

Methodology

Using beef processing as a case study to understand the shift from a conventional to a smart manufacturing for meat processing, we developed two skills frameworks—a conventional skills framework (CSF) and a smart skills framework (SSF).

To develop these frameworks, we followed five steps.

Step one: Analyzing meat processing

The first phase of the research involved a literature review aimed at identifying the unit operations involved in both conventional and smart beef processing. This revealed the unit operations, tasks, skills, and configurations of both conventional and smart meat processing plants. To guide this process, we adopted an analytic framework that assessed the literature relative to the following areas of inquiry:

- Conventional beef processing: This included the associated unit operations, configurations, worker tasks, and required skills.
- Smart beef processing: This focused on the automated and robotized operations, and the evolving worker tasks and skills required in these environments.
- Search criteria: This included publication titles, keywords, and abstracts addressing conventional and smart manufacturing in meat plants, and the role of automation and robotics in meat manufacturing.
- Source selection: This involved prioritizing academic peer-reviewed journal papers, grey literature, industry reports, and government web-based sources.

We analyzed and reviewed over 150 academic sources, grey literature, reports, and government documents to inform the development of our CSF and SSF.

Step two: From operations to skills

The second step involved detailing the tasks associated with key conventional operations and then linking these tasks to the specific skills required of workers. To determine these skills, we referred to the Occupational Informational Network (O*NET), hosted by the U.S. Department of Labor.[1]

The O*NET framework is based on seven distinct skill types, categorized as either basic or cross-functional skills. Basic skills are those needed for learning, whereas cross-functional skills enhance performance across multiple jobs or roles.[2] In addition, we added a general skills category, which includes skills such as hand–eye coordination to perform accurate cuts, handling repetitive tasks, and constantly operating sharp equipment. Information from O*NET was further supplemented by a review of publicly available job postings. Table 1 provides a breakdown of O*NET skill categories.

Step three: Configuring a smart manufacturing process

In the third step, we identified conventional unit operations that are becoming automated. These smart unit operations were determined through a review of academic and grey literature related to the application of robotics in meat manufacturing. Based on this review, we identified key robotic technologies, the tasks they perform, their level of automation, and their technology readiness levels (TRLs). TRL definitions are provided in Table 2.

After establishing these smart unit operations, we used the O*NET framework to develop a new skills matrix. This matrix identifies skills that will remain common through the transition to smart processing, skills that will be displaced (i.e., rendered obsolete), and new skills that will be required to perform smart unit operations.

Table 1

O*NET skills breakdown

Cross-functional skills	Basic skills
Complex problem-solving skills: Identifying complex problems, evaluating options, and implementing solutions.	**Content skills:** The background knowledge to work and acquire skills in different domains (e.g., active listening, mathematics, reading, science, speaking, and writing).
Resource management skills: Allocate resources efficiently (e.g., manage financial reports, material resources, personnel, and time).	**Process skills:** The application of knowledge and skills in different domains (e.g., active learning, critical thinking, and monitoring).
Social skills: Capacities to work with others toward a common goal (e.g., coordinating, instructing, negotiating, and service).	
System skills: Understand, monitor, and improve technical systems (e.g., decision-making, system analysis, and evaluation)	
Technical skills: Set up, operate, and correct machines and technology (e.g., maintenance, selection, installation, operation, control, analysis, monitoring, programming, quality control, repairing, and troubleshooting)	

Sources: U.S. Department of Labor; The Conference Board of Canada.

1 U.S. Department of Labor, "About O*NET."

2 U.S. Department of Labor, "Browse by Basic Skills"; and U.S. Department of Labor, "Browse by Cross-Functional Skills."

Step four: Defining human–robot interactions

To understand how the transition to smart manufacturing will affect working conditions, we categorized the human–robot interactions (HRIs) associated with each smart unit operation. HRIs characterize the degree of automation associated with a particular task and the type of interaction required of the worker. Smart unit operations were categorized according to four HRI categories: co-existence, sequential, parallel, and collaborative.

Step five: Validation

In a final step, we validated our skills framework through a series of expert interviews. We interviewed a total of 12 industry and academic experts. Participants were selected based on their expertise in robotics and automation in the beef industry in North America, Europe, and Australia.

Experts were asked about both primary and secondary beef processing, human–robot interactions, and the impact of automation on work conditions and skill requirements.

The interviews were carried out virtually between July and November 2024 and ranged from 33 to 62 minutes. All interviews were conducted and transcribed using Microsoft Teams. In total, this research generated 530 minutes of interview recordings. This resulted in 519 pages of transcripts comprising 88,838 words. Transcript coding and analysis for this study were performed using NVivo.

Table 2

Technology readiness level (TRL) definitions

TRL	Description
1	Basic principles of concept are observed and reported
2	Technology concept and/or application formulated
3	Analytical and experimental critical function and/or proof of concept
4	Component and/or validation in a laboratory environment
5	Component and/or validation in a simulated environment
6	System/sub-system model or prototype demonstration in a simulated environment
7	Prototype ready for demonstration in an appropriate operational environment
8	Actual technology completed and qualified through tests and demonstrations
9	Actual technology proven through successful deployment in an operational setting

Sources: Alberta Innovates; The Conference Board of Canada.

Appendix B

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Email: accessibility@conferenceboard.ca

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