Development of a Comprehensive Toolkit for Evaluating Workplace Musculoskeletal Injury Interventions: Swine Injection Technologies as a Test Case

Report on a WCB Manitoba Research and Workplace Innovation Program Project

Submitted to the Workers' Compensation Board of Manitoba
by Dr. Catherine Trask,

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Research Team

This project was completed through the efforts of several investigators:

- Bernardo Predicala, Investigator, U of S/ Prairie Swine Centre, SK
- Lee Whittington, Investigator, U of S/ Prairie Swine Centre, SK
- Brenna Bath, Investigator, U of S, SK
- Erika Penz, U of S, SK
- Olugbenga Adebayo, PhD Student, U of S
- Stephan Milosavjlevic, Investigator, U of S
- Catherine Trask, Investigator, U of S, SK
- Xiaoke Zeng, Research Assistant, U of S
- Aaron Kociolek, Investigator, U of S, SK
- Abisola Omoniyi, Research Assistant, U of S

Stakeholder Advisory Group

In addition to the investigator team, this study benefitted from the contributions of several industry stakeholders who provided insight into the swine industry and helped facilitate many aspects of the study. More details on the work of the Stakeholder Advisory Group is found in the methods section.

- Janice Goldsborough, Manitoba Pork Council
- Andrew Dickson, Manitoba Pork Council
- Bobbie-Jo Porter, Personnel Manager, OlySky (Pork Producer), SK &MB
- James Battershill, Keystone Agricultural Producers of Manitoba
- Harvey Wagner, Sask Pork Development Board
- Bridget Gray, Sask Pork Development Board
- Ravneet Kaur, Sask Pork Development Board
- Gail Archer-Heese, SAFE Work Manitoba's SAFE Farm Coordinator
- Bruce Ceilen, WCB Manitoba
- Joanne Machado, WCB Manitoba
- Korine Talbot, Veterinarian, Hylife (Pork Producer), MB
- Tatjana Ometlic, Production Worker, Prairie Swine Centre, SK
- Marcel Hacault, CASA
- Miles Beaudin, Manitoba Agriculture, Food and Rural Development Livestock Division
- James Battershill, Keystone Agricultural Producers of Manitoba

Executive Summary

The issue: injury prevention in pork production

Over the past several years, the Canadian pork industry has rapidly developed from small family farms into large-scale, modernized production systems; requiring major process changes and technological advancements throughout the pork value chain, i.e., from the pig farm all the way to the consumer. While these innovations in the production system have impacted worker health and safety these effects can be difficult to quantify especially when needed to make business decisions on mitigation strategies. Agriculture in general, and pig farming in particular, have many risk factors for musculoskeletal injury and disorders. Being a production-oriented and economically-driven industry, the rapid intensification in pork production has continually introduced new processes and equipment, although the pace of developing workplace health and safety evaluation tools to implement injury prevention interventions has not kept up with progress on the production side. In order to evaluate workplace health and safety relative to improvements in productivity this project developed a decision tool applicable to new workplace technologies. The tool is multidimensional, incorporating implementation costs, productivity changes, health and safety impacts, and worker feedback and preference. The test case for this assessment toolkit was needle-less injectors, a timely and archetypal technological change in swine production.

The specific study objectives were:

1) To investigate the implementation of needle-less injectors in terms of cost, productivity, injury rates, biomechanical exposures, and worker preference;
2) To develop a suite of decision-making tools for evaluating the occupational health and safety benefits, as well as business impacts, of new technologies;
3) To disseminate the toolkit to pork production and other livestock stakeholders.

Project activities: stakeholder consultation

This project involved both multi-disciplinary research methodologies and collaboration with an advisory group of industry stakeholders. Stakeholders came from swine producing enterprises and producer organizations, agricultural health and safety organizations, and included both production workers and vets. These stakeholders were involved in development of the project proposal, and additional swine and agriculture stakeholders were recruited as the study progressed. Three meetings were held to: 1) adopt a terms of reference and plan project activities, 2) present protocols and refine data collection methods; 3) interpret results and plan dissemination strategies.

Project activities: data collection and analysis

Evaluation components were carried out in phases to match the participants and data collection methods. Barn measurements of swine worker participants performing injections by conventional and needle-less methods were made to assess the exposure to upper limb disorder risk factors and the productivity of each method. Muscles forces were assessed using portable surface electromyography (EMG) on the flexors and extensors of both arms. Wrist and finger posture and movement speed were assessed using a posture sending glove that recorded movements during injections. TRask Swine workers were also video recorded while performing the injections measurements; this was used to determine the cycle time or duration of the injection task using each method.

Swine industry Workers Compensation Board (WCB) claims rates were calculated for needle/syringe injury (i.e. 'needle stick') and upper limb musculoskeletal disorders (such as carpal tunnel syndrome) Rates were compared before and after the implementation of needle-less injectors. Eleven swine production workers and 7 barn managers were interviewed by telephone to gather their perceptions and feedback on advantages and disadvantages of the needle-less injector and its implementation. A cost benefit analysis was performed to determine the economic impact of needle-less injection. Costs included equipment start-up cost, equipment maintenance cost, training cost, needle disposal cost, labour cost, and average injury-related cost per year. A web-based decision making tool was developed based on the economic evaluation, and incorporating findings from all phases.

Summary of Findings

- Despite initial hypotheses that the needle-less injector would introduce new musculoskeletal risks, we found either no difference or decreases in muscle force (24-26%) and movement speed (7-15%).
- Productivity, as measured by injection task duration, was more than twice as long expert conventional needle users than expert needle-less injector users.
- After implementation of the needle less injector, there was no change in the rate of musculoskeletal disorders, however, the rate of needlestick injuries went down substantially.
- Worker feedback suggested that aspects of the needle-less injector could promote or inhibit use depending on the context; for example, maintenance can be a barrier if you need to send a broken unit out for repair, but many issues can be addressed by skilled in-house maintenance staff. Primary recommendations pertained to increasing portability, enhancing ease of cleaning, and implementing feedback mechanisms to indicate injection success/failure and low vaccine levels.
- The economic net benefit of needle-less injection was slightly higher than that of conventional needle, although these benefits are limited to larger facilities (greater than 400 sows). Due to the large start-up costs of the needle-less injector, the economic benefits begin accruing after the first year.

Dissemination of findings

Project findings were disseminated to scientific audiences through scientific publications and presenting results to audiences of ergonomists, occupational health researchers, epidemiologists, and biomechanists. Dissemination to industry stakeholders centered on the development and promotion of a web-based decision making tool to help producers decide whether to implement new technology in their operations. Webtool promotion involved linking to stakeholder's websites; inclusion in stakeholder newsletters and social media channels; presenting during Prairie Swine Centre's 'spring tour' of Western Canadian producer group meetings; and the a presentation at the 2019 Saskatchewan Pork Symposium.

The webtool can be accessed via the Prairie Swine Centre website:

Project Background and Introduction

Agriculture is hazardous

Agriculture is widely acknowledged as "one of the most hazardous occupations worldwide", both in terms of acute and chronic musculoskeletal disorders and injuries.(1) A literature review of musculoskeletal disorders (MSD) among farmers reported 91% lifetime prevalence for any type of MSD, and one-year prevalence of 77%.(2) In Manitoba, the time-loss injury rate for Agriculture and Forestry is 71% higher than the overall rate for all industries. (3)

MSDs in agriculture impact worker productivity and quality of life, both internationally and in Canada. Sprains and strains account for 28.2% of the approximately 200,000 time-loss injuries on US farms, and 43% of all agricultural injuries are categorized as 'over-exertions' or MSDs.(4) Livestock agriculture introduces unique risks; a study of Swedish pig and dairy farms found the 12-month prevalence of any MSD to be 78% in swine workers, with the most common injuries being in the upper extremities (62%) and the back (57%).(5) Similarly, Danish swine workers were also found to have high rates of MSD.(6) A recent pilot study of industrialized Canadian swine workers found a 12-month prevalence of 92% of MSD and 58% of respondents reported having their activities interrupted by MSD symptoms.(7) MSDs are the most common cause of work absence in self-employed Dutch farmers, (8) and Irish farm income is shown to be lower when operators have MSD-related disability.(9)

Intensification trends in agriculture

Between 2001 and 2011, the number of pig farms in Canada decreased from 15,472 to 7,371 (~25% decrease), but the total number of pigs produced increased from 13.9 million to 15 million (~7% increase) indicating an overall trend of consolidating pork production into larger barns. This trend is even more pronounced in Manitoba and Saskatchewan, where the respective drop in the number of farms was 7388 to 6040 (~18% decrease) and 1677 to 930 (~44% decrease). During this time the number of pigs increased from 2.5 million to 2.9 million (~16% increase) and 1.1 million to 1.4 million (~27% increase) for Manitoba and Saskatchewan, respectively.(10, 11) This trend of industrialization is also seen in other industrialized nations such as Sweden.(5) Combined with globalized commodity markets' downturn in pork prices (12), this creates a context of very low profit margins and high production pressures. It has been noted in other industries that when the primary motivations are **driven by economics, global competition,** and **production**, OHS and ergonomics may be seen as a threat or regulatory barrier rather than as a benefit.(13) It is therefore imperative to consider business needs when pursuing OH&S goals.

These economic pressures also drive **technological advancement,** especially in those areas that will enhance productivity or reduce production costs. For example, needle-less injectors are now available to replace hypodermic needle injections. These devices can eliminate needle-stick injuries in workers and broken needle contamination in meat, and may also increase productivity. However, the repetitive, forceful gripping required during needle-less injecting, in addition to other postural or repetitive strain due to task specialization, may introduce new hazards in the form of greater risk for musculoskeletal injury. There is evidence that industrial intensification and its process changes may either increase existing MSD exposures or introduce new ones. In dairy farming, industrial intensification has been shown to **change MSD exposure profiles**,(10, 12) as well as to increase (14) or change the location (15) of reported MSD (e.g. from the knees to the back). Swedish dairy workers, for example, demonstrated increasing rates of MSD from 83% in 1988 to 90% in 2002.(14) This change was concurrent with increased task time and musculoskeletal exposure duration using modern milking equipment.(16) As livestock intensification may carry increased risk, research is needed to ensure technological advances take worker health and safety into account while assessing and acknowledging economic factors.

Comprehensive multidimensional evaluation: evaluating OHS impacts of new technology

The need for ergonomic interventions that limit musculoskeletal risk factors in agriculture (and particularly animal handling work) is widely acknowledged.(17, 18) There is evidence that ergonomic interventions can be cost-effective for a business, but the quality of economic evaluations is frequently poor and usually does not describe the economic benefits.(19) Despite agreement that a higher quality of ergonomic intervention research is required,(20) most intervention studies focus solely on musculoskeletal exposure with and without modified tools or equipment during lab-based or simulated work (21-24), or in small field studies.(25, 26) Although changes in musculoskeletal exposure are a valuable measure of an intervention's effects, any efforts to effectively implement and promote OH&S interventions in the swine industry need to: demonstrate sensitivity to the intensive production context; consider the work culture and attitudes of users; examine potential unintended consequences; and demonstrate a return on investment in order to motivate implementation.

Safety interventions (such as a needle-less injector) are often multifaceted and introduced into complex environments; personal factors such as self-efficacy and skills, as well as organizational factors such as management support and device accessibility can impact the degree to which an intervention is implemented (27). Because of the intensive context of animal production, economic evaluations of new methods like needle-less injectors have held a lot of research interest in the swine industry (28). Integrating ergonomics, worker health, and safety with corporate goals like quality and productivity is key to motivating adoption of safer practices and equipment (13). However, *economic* evaluations of ergonomic interventions are rare (29), highlighting the need for a more comprehensive approach to workplace intervention evaluation.

A comprehensive decision making tool needs to incorporate all the dimensions of successful implementation, as well as those which influence decision-making regarding adopting a new technology. When aligned with engineering designs and goals of the organization from the outset, ergonomic interventions are reported to result in effective lessening of symptoms, lost work days and claims for injuries during work (30), as well as better business performance (31, 32). However, effective impact of ergonomics (and OH&S) interventions requires communication and agreement among decision-makers; a suitable means of knowledge translation is therefore needed to ensure a common stance among stakeholders (30, 33, 34). In a production-driven private enterprise, cost-benefit analysis is a common metric and could form the foundation for discussion and adoption of new technology. In its final format, a toolkit to aid in this decision-making needs to be not only be comprehensive, but also understandable, usable, and accessible to knowledge users. For example, web-based decision-making tools are available for health care (35). However, to our knowledge, this approach has not yet been applied to OH&S in intensive livestock production.

Swine injection tasks: a timely and industry-relevant example
Injection for nutritional supplements, immunizing animals, and providing treatment to sick animals is a standard practice in the swine industry (and livestock production in general). Historically, injection was carried out by barn workers by drawing liquid into a hypodermic syringe and injecting (subcutaneously or intramuscularly) into the animals. However, in an alternative needle-less method, pressure forces a jet of vaccine or other liquid through the dermal layer and into the subcutaneous tissue.(36) Although needle-less injection was developed for humans nearly a century ago, it is not widespread due to patient preference.(37) The technology was likewise slow to transfer to agriculture, though in the past decade adoption has increased. A recent review of needle-less injection methods notes that it: eliminates broken needles in meat (enhancing food safety of subsequent pork products), needle-stick injury, and needle disposal; delivers a more consistent, lower dose of vaccine; and causes less stress in animals.(36) There is also a suggestion of greater immunological effects using needle-less injectors,(36) although this finding is inconsistent.(38) However, the review authors also note several disadvantages of needle-less systems: substantial equipment purchasing costs; exhaust gas infrastructure for pneumatic devices; increased training and maintenance needs, and worker preference for a known method (i.e. needle injection).(36)

Figure 1: photo of the devices and schematic of their function: a conventional 'sharp' needle (left) and a needle-less injector with amplifier and compressor cart (right)

Although needle-less injectors eliminate needle-stick injuries and needle contamination of meat (benefits), they may introduce an unintended consequence of increased frequency of grip force and awkward postures (costs in terms of WCB claims and lost productivity). Repetitive movements during work tasks have been consistently shown to increase risk of musculoskeletal disorders.(39, 40) Such movements may be intensified on industrialized farms. A study of modern, intensive pork production observed hand grip frequencies of 30 per minute during "piglet processing" (an injection-intensive task), and between 10 and 15 per minute during “herd health checks” (which involves injections).(7) This kind of repetitive and forceful gripping is a risk factor specifically for upper limb musculoskeletal disorders including carpal tunnel syndrome.(41) Increases in gripping force and frequency with needle-less injectors may negate the needle-stick benefits, but an empirical comparison is required to make any conclusions. Needle-less injector use is on the rise in agriculture, but they are not implemented in all barns due to uncertainty about cost-benefit tradeoffs. This makes needle-less injectors an ideal current technology to evaluate. To our knowledge, no evaluation of needle-less injectors has included worker health issues such as needle-stick injuries and MSD as well as economic cost/ benefits, a worrisome gap at a time when needle-less injection is growing more popular.

Intensification of Canadian pork farms (11) changes the labour context from small independent farms (where family members perform a variety of tasks) to an employer model (where workers perform a narrow range of tasks within specialized roles); this intensification may further contribute to already high rates of musculoskeletal disorders among pig farmers (5, 6). Intensification has potential to impact worker health in Manitoba, where 47% of all WCB claims are currently caused by overexertion or repetitive motion (3). It also tips economic conditions to favour investment in specialized equipment, technology, and facilities. The context of intensive livestock operation in Manitoba may carry new risk factors for injury, but it also presents an opportunity to address the challenges of new technology introduction, and to include occupational health and safety in decisions about implementing new technology. However, there is no current guidance for livestock producers, and a production-oriented cost model may not account for injury and illness. Developing a comprehensive decision-making toolkit that accounts for occupational health will enable livestock stakeholders to implement technologies that enhance economic goals and the health of workers. Since there are questions limiting implementation in all barns, needle-less injectors are a timely and industry-relevant test case for developing and applying this toolkit.

Research Objectives

While investigating the differences between needle and needle-less injection processes in terms of cost, injuries, productivity, and musculoskeletal exposures, this project developed a suite of decision making tools to guide implementation of new technology in intensive livestock operations. The specific objectives were:

1) To investigate the implementation of needle-less injectors in terms of cost, productivity, injury rates, biomechanical exposures, and worker preference.

2) To develop stakeholder-driven decision-making tools for evaluating new technology in terms of the Occupational Health and Safety benefits as well as business impacts.

3) To promote the decision-making tool among Canadian pork production stakeholders

Project activities

This project involved both typical research methodology and the collaboration with an advisory group of industry stakeholders. The methods for both of these activities are described in this section.

Stakeholder Advisory Group

To ensure that the results of this study remain relevant to the pork industry, the research team recruited and maintained strong industry connections through the use CIHR's integrated knowledge translation (KT) approach, engaging stakeholders throughout the research process (42). Forming partnerships with key stakeholders was intended to produce results that are more relevant and more likely to be put into practice. This proposal involves ongoing collaborative interaction between decision-makers and researchers that will result in mutual learning through the process of planning, producing, disseminating, and applying existing or new research in decision-making.

The original grant proposal was developed in collaboration with the Prairie Swine Centre (along with co-investigators Whittington and Predicala), industrial partners Maple Leaf and OlySky Farms, the Saskatchewan Pork Development Board and the Manitoba Pork Board, and the Keystone Agricultural Group. A full list of the SAG members and their affiliations is provided in the acknowledgments section.

In addition to specific input during grant development, several representatives from Manitoba and Saskatchewan were invited to form a stakeholder advisory group (SAG) to help inform and guide key stages in the research process.

The SAG participated in three meetings:

1. Initial planning meeting to set project goals and parameters and ensure stakeholder needs are addressed
2. Pre-data collection meeting to present data collection plans for feedback that will improve the methods and ensure resulting data is industry-relevant
3. Post-data collection to present preliminary results for stakeholder interpretation and development of dissemination plans

The work of the committee was guided by a terms of reference which was co-created and approved by the group at the first meeting. A copy of the terms of reference document is found in the Appendix.

Research Data Collection

To develop a comprehensive decision making tool, this project used a combination of quantitative and qualitative data collection strategies: 1)electronic measurement of muscle activity, grip forces, and hand/arm postures; 2)time-and-motion productivity analysis of each method; 3)needle-stick and upper limb musculoskeletal injuries; 4)key informant interviews to determine barriers and facilitators to safe injection device adoption; and 5)an economic analysis of the costs and benefits of the new technology. The resultant decision-making tool was based on a logic model as shown below.

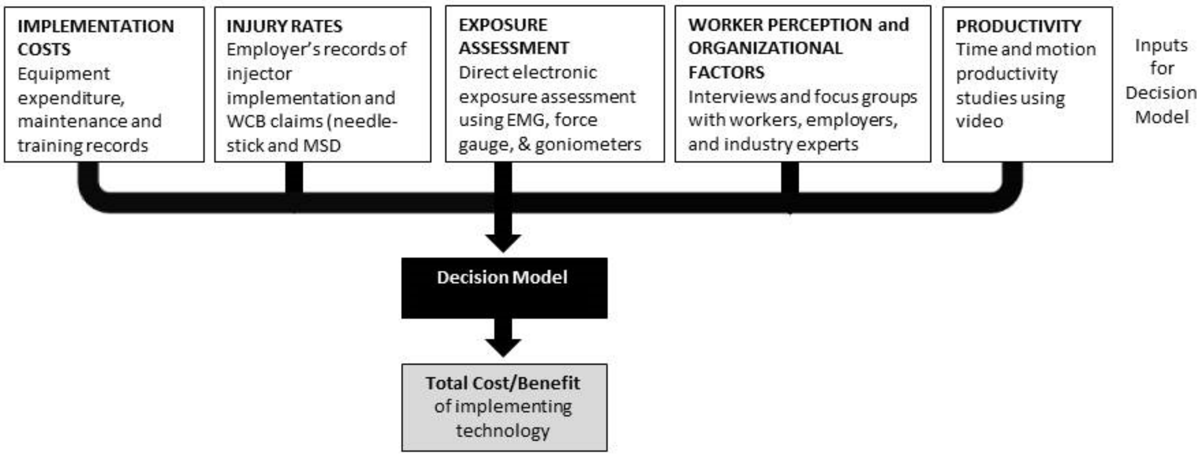

Figure 2: Logic model for comprehensive decision-making toolkit for implementing new technologies in Pork Value Chain. A related web tool will allow users to enter inputs for their situation and estimate total cost-benefit.

Ethics

All participants of this project were adult volunteers who gave informed consent after having their questions answered. All data collection methods were approved by the University of Saskatchewan Behavioural Research Ethics Board.

Ergonomic Exposure and Productivity: Barn Measurements

Three swine workers familiar with swine injection tasks and with needle injectors participated; they were novices with the needle-less injector system. Participants completed four hours of orientation, including reading the instruction manual, watching demonstrations of use, and practicing on cadaver and live pigs. Conventional and needle-less injections methods were tested during two common tasks: piglet processing and nursery pig injection.

Muscle forces were inferred from surface electromyography (EMHG) measurements. The extensor and flexor muscles of the dominant and non-dominant hands were measured during all injections using a portable data-logger (SX-230 surface electrodes and MWX8 data-logger, Biometrics Ltd.). EMG was calibrated or 'normalized' using a series of maximum voluntary contractions. All muscle activity was subsequently expressed as a percentage of maximum voluntary contraction (%MVC). Position and movement of the dominant fingers, hand, and wrist were measured using an instrumented data glove (CyberGlove II, CyberGlove Systems, San Jose, CA) which transmitted data via wifi during all injections. Once fully instrumented but before data collection, the glove was calibrated using a set of static calibration poses; goniometers were used to confirm at least two flexion/extension angles for the wrist, PIP, and MCP, and radial-ulnar deviation for the wrist.

Concurrent with the direct measurement of all injections was video recorded and used to determine the duration of injection for both injector types and both injection tasks (vaccination and piglet processing).

Generalized estimating equations (GEE) were used to investigate the effect of different injectors on workers' productivity and ergonomic exposures. GEE models presented here used the exchangeable correlation structure and non-nested repeated measures within 'worker' and 'pig. All analyses were conducted using R 3.4.4.

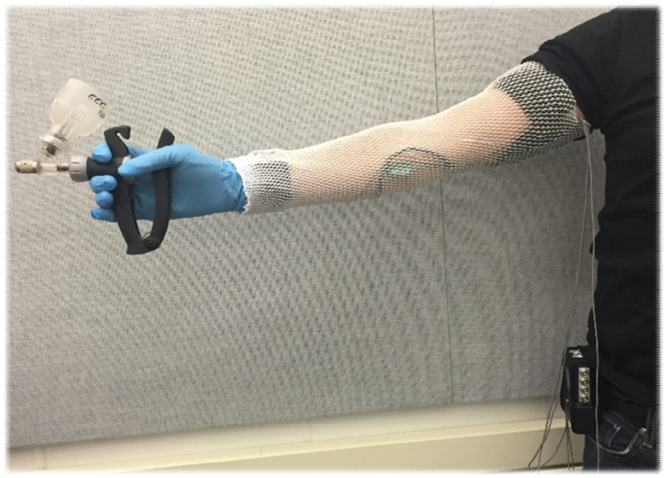

Figure 3: full instrumentation showing the EMG electrodes (green on the forearm) and posture measuring glove shown (underneath a protective nitrile glove). The participant is holding a conventional injector

Injury Rates

Historical Workers Compensation Board claims data from the swine industry was used to investigate rates of needle/syringe injury (i.e. 'needle stick') and upper limb musculoskeletal disorders (for example, carpal tunnel syndrome, rotator cuff syndrome, finger/wrist tendonitis or tenosynovitis). The bulk of f needle-less injector implementation occurred in 2010. Injury rates were calculated for the years 2004-2009 ('pre-implementation') and for the years 2011-2016 ('post-implementation').

The average claims cost, including both healthcare and wage replacement, was calculated for both injury types. Average costs for both needle-stick injury claims and upper-limb musculoskeletal disorder claims were calculated in 2017 dollars.

Economic Analysis

Cost data were gathered from three sources: video data collected during barn measurements, WCB statistics on needle-stick injuries and upper-limb musculoskeletal disorders before and after implementation of needle-less injectors (both described above), and a survey of cost data among swine producers. Convenience sampling techniques were used to recruit key informants from 5 swine enterprises in Saskatchewan and Manitoba for the survey. Snowball sampling was used to identify additional informants when an informant could not provide full cost data.

Cost benefit analysis was performed from the perspective of the swine producers and reported in 2017 Canadian dollars. Benefits were measured as productivity in terms of the number of pigs produced per year using each injector method. Benefit (revenue from pigs produced in a year) is determined by multiplying the market price of the pigs by the number of pigs produced per year (including any losses resulting from broken needles). Costs included equipment start-up cost, equipment maintenance cost, training cost, needle disposal cost, labour cost, and average injury-related cost per year.

Worker and Management Interviews

Worker interviews were conducted by telephone while the participant was at work.
Both production workers (11) and barn managers (7) were recruited starting with a list of key informants (many of whom were also Stakeholder Advisory Group members). Snowball sampling was used to expand the sample size and identify those within an organization that had the most experience with needle-less injectors. Interviews included open-ended questions designed to explore: **Worker preferences** and perceptions regarding needle-less injector use in the barns; **Disadvantages**, difficulty, barriers, and obstacles; **Advantages** of needle-less and facilitators/enablers to adoption of the needleless injector; and **Experience** with the needleless injector regarding training, safety, logistics, adaptability, and satisfaction with both tools. Interviews were audio-recorded and transcribed verbatim, then qualitative data analysis methods were applied using QSR Nvivo Software. Responses were coded into themes and grouped into Barriers, Enablers and Recommendations.

Results and Interpretation

Ergonomic Exposure: Barn Measurements

The conventional needle was successfully measured by EMG for 144 nursery pig vaccinations and by 162 piglet processing injections; the posture glove successfully measured 108 nursery pigs and 144 piglet processing injections. The needle-less injectors was successfully measured by EMG for 144 nursery pig injections and 162 piglet processing injections; the posture glove measured 108 nursery pig injections and 144 piglet processing injections for the needle-less injector.

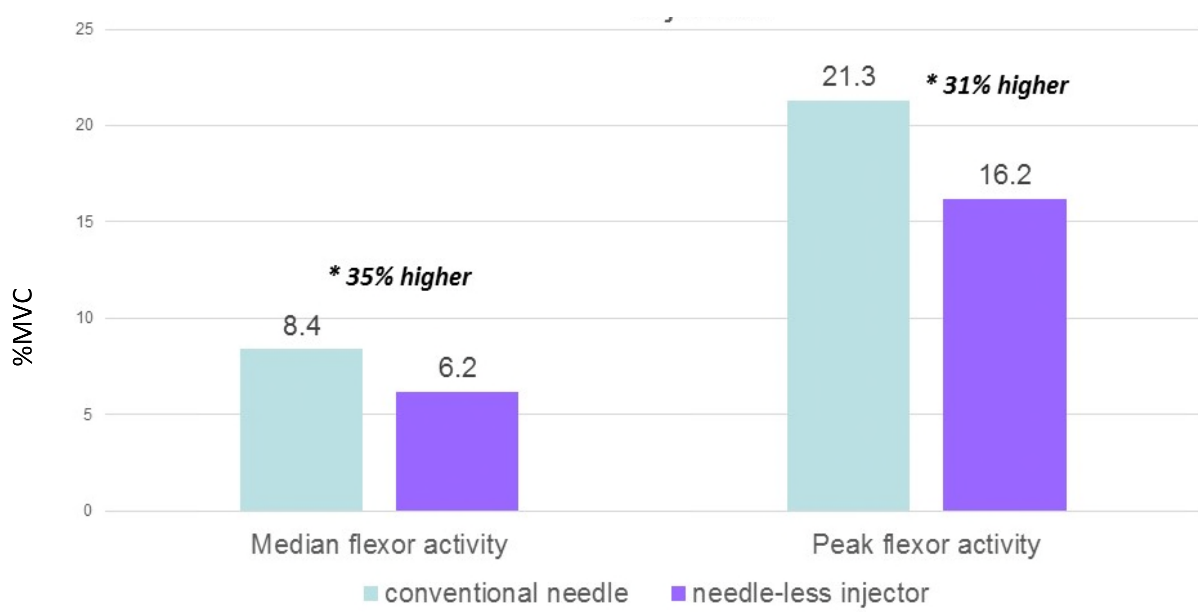

Figure 4: Forearm flexor muscle activity for conventional and needle-less injection methods. Median (50th percentile) muscle activity is 35% higher with the conventional needle. Peak (90th percentile) muscle activity is 31% higher with the conventional needle. Both differences are statistically significant as assessed by generalized estimating equation.

EMG is used to estimate muscle force, excess force is considered a risk factor for musculoskeletal disorders like carpal tunnel syndrome. This report focuses on the flexor muscle activity, since the tendons for flexor muscles run through the carpal tunnel.

The posture glove has 18 separate sensors to assess the various joint movements of the wrist, hand, and fingers. In this report, we focus on peak flexion of the trigger fingers (index and middle fingers) and the speed of the wrist and trigger fingers. Peak flexion shows the near-maximal range of motion of the joints during the squeezing motion involved in activating the injection trigger. There were no statistically significant differences between injection types.

Flexion speed is related to friction development in the tendon sheaths; since friction can lead to inflammation, higher speeds are considered a risk factor for musculoskeletal disorders like carpal tunnel syndrome. We found that, depending on the specific joint, flexion-extension speed was 8-15% higher with the conventional needle than with the needle-less injector.

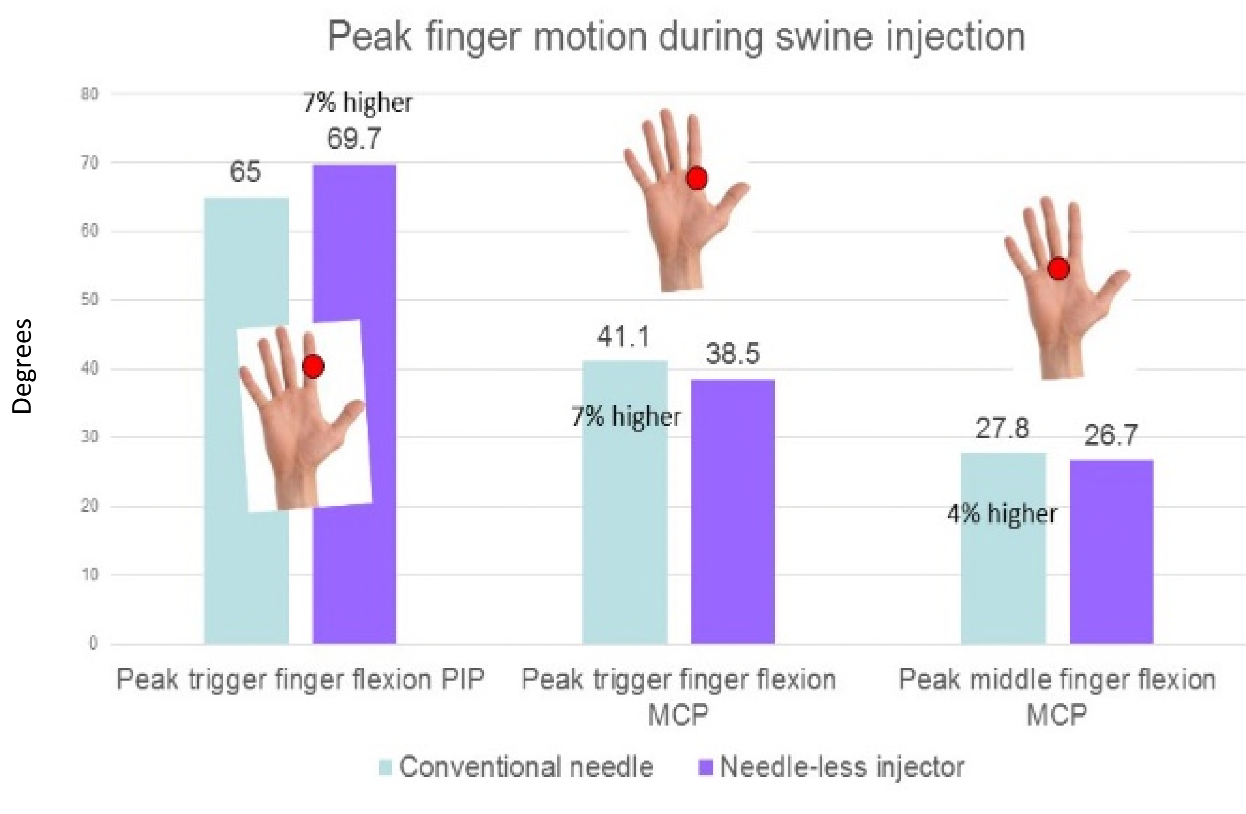

Figure 5: Comparison of injection methods as assessed by peak (90th percentile) flexion of the: index (trigger) finger proximal interphalangeal joint (PIP, left columns); index (trigger) finger metacarpal-phalangeal joint (MCP, middle columns); and middle finger metacarpal-phalangeal joint (MCP, right columns). There were no statistically significant differences between injection types.

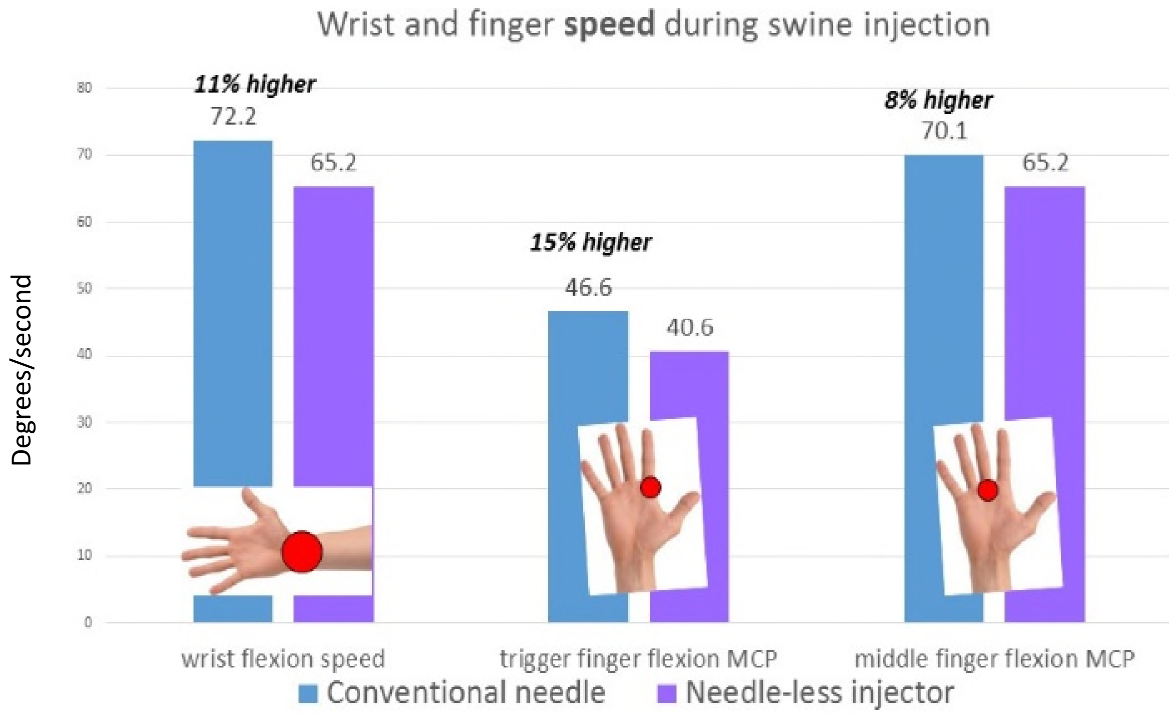

Figure 6: Comparison of injection methods as assessed by mean flexion/extension speed at the: wrist (left columns); index (trigger) metacarpal-phalangeal joint (MCP, middle columns); and middle finger metacarpal-phalangeal joint (MCP, right columns). Speeds were statistically significantly higher during conventional needle injection, with differences ranging from 8-15%.

Productivity

The time to complete each swine injection tasks is an important measure of productivity and thus, a potential benefit of adopting a new technology. For the piglet processing task, we found no significant differences between injector types. When investigating the nursery pig vaccination task, we found no

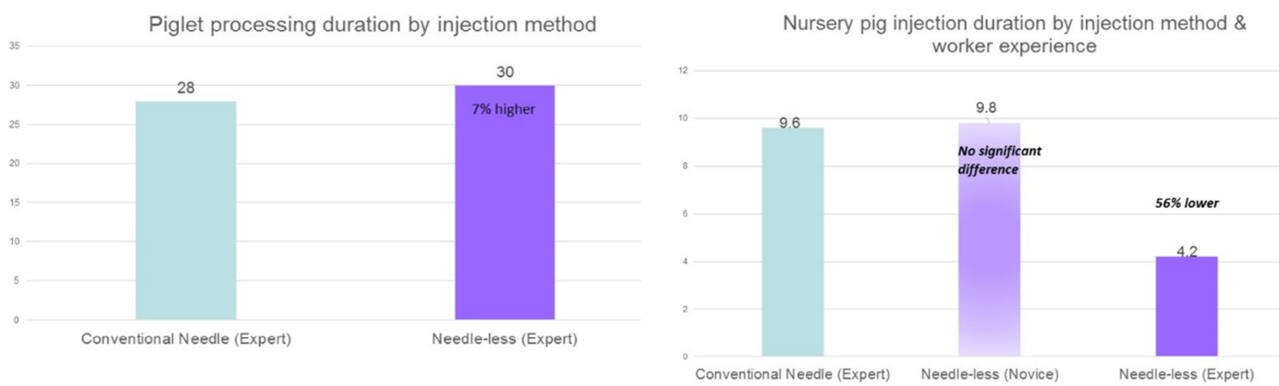

Figure 7: Comparison of the cycle time (injection duration) by injector type and user expertise. For piglet processing (right), there is no significant difference between injector types. For nursery pig vaccination (left), duration is 56% lower for expert needle-less users when compared to expert conventional needle users.

significant difference for novice users (i.e., those that had used the needle-less inject tor for less than a month). However, for expert users, they were able to work substantially faster; expert users of the needle-less injector had 56% lower cycle times (i.e. injection duration) when compared to expert conventional needle users.

Injury Rates

The main injury types considered in this analysis of WCB claims data were needle-stick related injury and upper limb musculoskeletal disorders like carpal tunnel syndrome. Although needle-less injectors help eliminate needle-stick injuries by eliminating sharps from certain tasks, we thought needle-less injection might introduce new hazards, such as higher repetition from faster injection, more forceful gripping, or other postural strain due to intensified task speed. However, we found that after implementing the needle-less injectors, the rates of needle stick injury went down from 2.13% per 100,000 fulltime equivalent employees (FTE) to 0.74%. Note that the needle-stick injury rate does not go to zero since there is still need for some needles in the barn for one-off treatments that are not appropriate for the needleless injector. However, when we investigated the claims rates for upper limb disorders, we found there was negligible change after the introduction of needle-less injectors (0.15% to 0.07%). WCB claims data also yielded the average healthcare and lost-wages cost for each type of claim: $230 for a needle-stick and $15,000 for an upper limb musculoskeletal disorder.

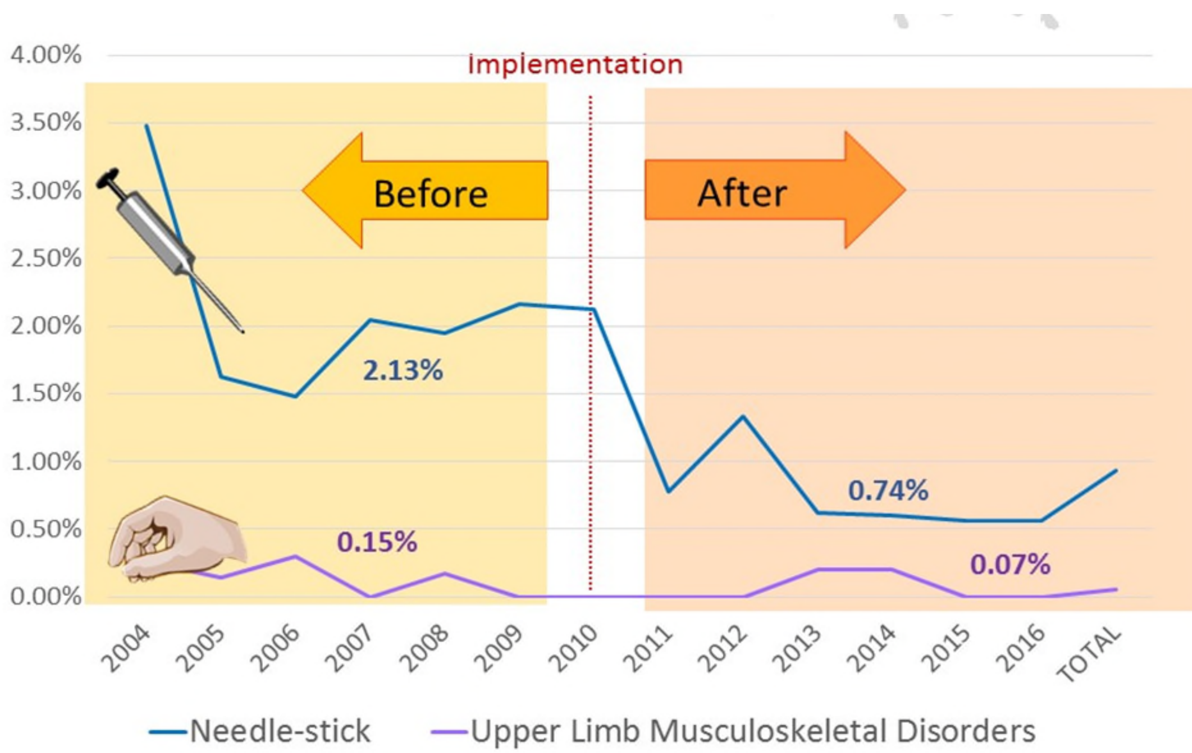

Figure 8: WCB claims rates for needle-stick injury (blue line) and upper limb musculoskeletal disorders (purple line) before (yellow background) and after (orange background) needle-less injector implementation (vertical red dotted line)

Economic Analysis

In cost benefit analysis (CBA), all benefits and costs are identified and expressed in monetary terms. This allows for direct comparison of costs and benefits and for the results of the analysis to be expressed in terms of a cost-benefit ratio, benefit-cost ratio, or net benefit (net present value) resulting from the intervention. For a CBA expressed as net benefits, the decision rule states that an intervention with a positive net benefit (i.e. positive net present value value) is worthwhile and should be undertaken; when comparing multiple interventions, the one with the highest net benefit should be undertaken.
The economic net benefit of needle-less injection was slightly higher than that of conventional needle, although these benefits are limited to larger facilities (greater than 400 sows). Due to the large start-up costs of the needle-less injector, the economic benefits begin accruing after the first year.

The benefit for both injector types is the number of pigs produced, which is slightly lower for conventional needle since during the rare case that a needle is broken off in the skin of a pig, the meat is considered 'contaminated' and the pig cannot go to market. Given this rare loss of benefit, the injections methods differed primarily by their costs. Our findings showed that the capital equipment costs were much higher for the needle-less injector, but this was offset by productivity benefits of faster pig injection when experts use needle-less methods. Considering costs and benefits together, we found the net benefit of needle-less injection to be slightly higher than that of conventional needle and likely to be the case for barns with more than 400 sows. Due to large start-up cost associated with needle-less injector, the benefits of this injection method is seen beyond 1 year of use.
This economic analysis provides some initial footing for future decisions on technology adoption in the swine industry; thus it provided the framework for the decision making web-tool developed for knowledge translation and dissemination of findings.

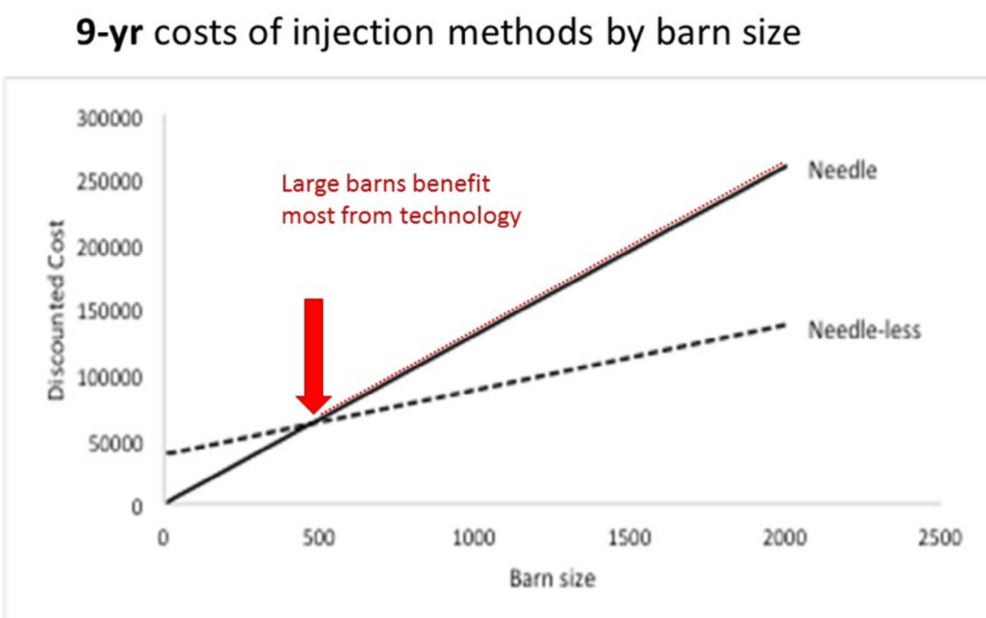

Figure 9: Cost benefit analysis over a range of barn sizes (expressed as numbers of sows) for conventional needles (solid line) and needle less injector (dashed line). Calculations were made from the swine producers' perspective and expressed in 2017 Canadian dollars. The red arrow indicates the barn size at which needle-less injectors start to be more profitable that conventional.

Worker and Management Interviews

Worker feedback suggested that aspects of the needle-less injector could promote or inhibit use depending on the context; for example, maintenance can be a barrier if you need to send a broken unit out for repair, but many issues can be addressed by skilled in-house maintenance staff. These interviews occurred within a context of, in some cases, quite long experience with needle-less injectors. Though the needle-less injectors are already implemented in most of the participants' barns the conventional needles and syringes are also still in use to deliver specific drug(s) to the pigs. Participants described that the needle-less injectors were used during the vaccination while the needles and syringes were used during antibiotics treatment of piglets/pigs. Both managers and workers consistently described the needle-less injector as the most preferred injection type; this method is also described in their quotes as "needle-free" "pulse-free" or "without needles".

Overall, perceived benefits mentioned by participants were classified as the "Facilitators" or "Enablers" of the new technology. These were described by participants as facilitating the use of the new technology. Workers' adoption of the new technology was primarily motivated by beliefs that it is safer, less complicated, and faster.

In terms of safety, workers described less risk of poking one's self or broken needles in animals. For example, when asked about benefits, one worker summarized:

> *"Safer. It's safer for the animal and safer for the people."* *Manager, Farrow to finish barn*

The needle-less injector was also considered less complicated for a first time user (i.e., user friendly);

> *"But actually on the job training is pretty fast, most people pick it up pretty quickly. You show them where the injection goes, and how to handle the gun, and it usually only take a few minutes before they got the hang of it."* *Manager, Farrow to finish barn*

Speed was also related to ease of use, for example, involving no changing of needles between pigs or worries about needle size:

> *"Because there's less of a chance of a broken needle going into the meat, into the pigs."* *Worker, Nursery barn*

Users of the needle-less injectors also described some barriers and limitations of needle-less devices. Respondents had varying views with different degrees of perceived drawbacks hindering work efficiency and productivity, concerns to health or some frustrations due to use of the needle-less injectors. The main themes for these disadvantages were bulkiness and lack of portability, slowdowns in productivity, and potential safety risks to workers.

Bulkiness and difficulty in handling was described by participants; it is usually difficult handling the needle-less device due to its bulkiness compared to the conventional needle and syringe that can be easily moved around within the pen. The new technology has many connecting parts that need to be moved around when performing the injection task.

> *"I would like it to be more moveable. I don't know, maybe a backpack or something, because right now we have ours on a cart."* *Worker, farrow to finish*

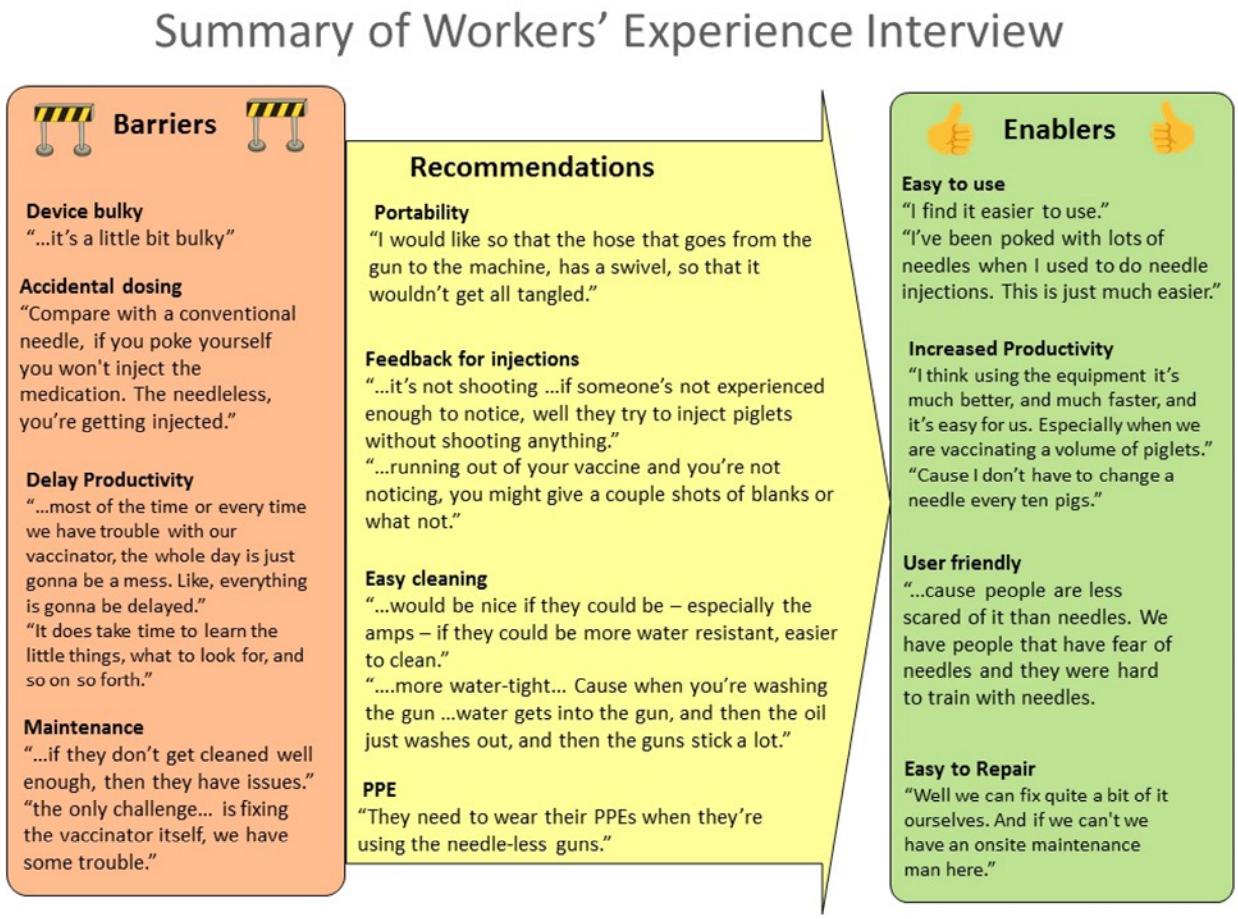

Figure 10: Themes emerging from worker interviews on the barriers and enablers for successful implementation of the needle-less injector, including some recommendations for improvement

The theme relating to work efficiency and productivity included comments on the needless injectors causing delays in work flow; down time was noted particularly at such periods when injectors are faulty and require fixing, as well as times spent on keeping them clean after use. Often times the needle-less injectors do not work as expected hence requiring repairs such as fixing of the O-rings or cleaning with vinegar and water if there is a blockage. The perception that the needle-less injectors may reduce productivity was expressed more by the manager and discussed under the theme "workflow delays".

> *"Sometimes if you have a gun that's malfunctioning, or it's plugged up. There is a bit of down time to fix them, whereas if you had just a syringe and a needle, you'd throw it away and get another one."*
>
> *Manager Farrowing Barn*

> *"It just takes time to clean after you used it, because it needs to be cleaned with vinegar and water. So it takes time."*
>
> *Worker Farrow to finish Barn*

"The only challenges that I really encountered was changing the bottom pieces out. It sometimes there's a rod inside of the. Sometimes the rod would fall out of place, and then it would take so long to build the pressure back up once you fix it again. It would take a long time to build pressure back up to be able to actually inject." *Worker Nursery Barn*

The 'health and safety' theme included comments on device having the potential to cause harm or injury to worker while performing the injection task. Managers and workers had overlapping views: for example, concerns about persons getting injured due to accidentally injecting themselves or co-workers, or injuries to fingers from pressure and prolonged handling of the injectors were identified.

"But for people, you got to make aware that it's dangerous, and once you shoot, it will shoot everything. Compared with a conventional needle, if you poke yourself you won't inject the medication…the needle-less, you're getting injected."

Managers, farrow to finish barn

"I know one of my co-workers in the past accidentally vaccinated themselves with it. And it caused a very big bruise, and it was very painful for her." *Worker, nursery barn*

"We've had incidents where people accidentally shot themselves, because sometimes the lock on the gun or the hand piece doesn't always work. And if you accidentally bump the nozzle, it will fire." *Worker, farrow to finish barn*

Preventive measures were suggested to help reduce the risk of accidental injecting while using the device: the use of personal protective equipment (arm guards) and self-awareness were recommended in performing the task:

"As long as everybody, like I said, wears their arm guards, I don't feel like they're overly dangerous. Even using them myself I've never felt like I was in a positions where I almost injured myself or injured somebody else." *Manager, farrow to finish barn*

Knowledge Translation and Webtool

Results were disseminated to industry and scientific audiences throughout the project as phases of the multi-method evaluation were completed. A summary of the scientific presentations and publications is listed in the Appendix.

Stakeholder participation

The stakeholder advisory committee was absolutely central in the disseminations of results to the industry. Stakeholders brought study summaries to colleagues within their organizations and to industry meetings, and in many cases were able to channel feedback from a broader audience. In most cases results summaries were short reports or powerpoint slides, but after the second meeting we also created a video and posted it on youtube so that stakeholders could access and share it more readily. (See https://www.youtube.com/watch?v=rbnTSEkXz0o)
At the conclusion of the study, a final youtube video was poster to summarize the project and introduce the webtool (See https://youtu.be/qOgENgXmL5w)

Webtool development

After all evaluation components were complete, the resultant decision making tool was translated into a web-based application where users (i.e. swine industry stakeholders) can enter inputs reflective of their situation, and using the economic algorithm developed in this study, receive an estimate of the cost-benefit that a certain innovation will deliver. The tool has a graphical-user interface and provides instructions and examples. The calculation is 'in the background' abstracted away from the user, but a user can toggle options and select links to open new tabs with information on how to select or estimate model inputs; all of this supplementary information includes the range of findings identified during the needle-less injector case evaluation.

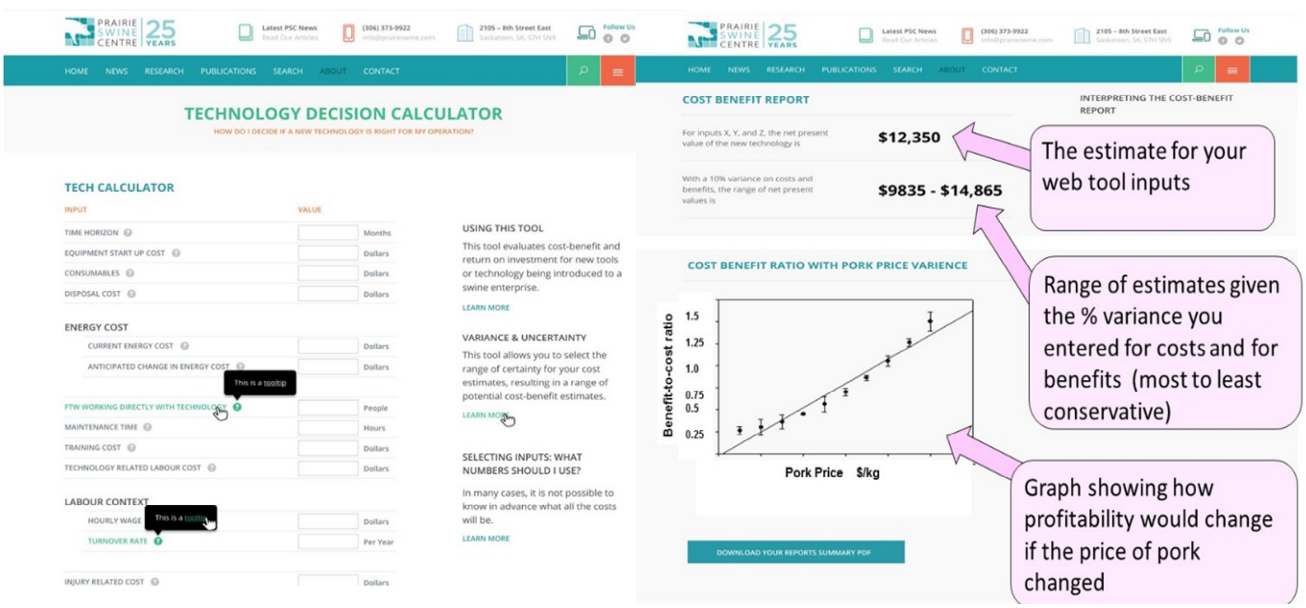

Figure 11: Screen shots of the webtool's main functional pages (left) user inputs and (right) report of results

After receiving feedback from stakeholders on a webtool mock-up, the tool was finalized as a 'beta version' and iteratively tested and refined by the study group. After substantial updates, the webtool was sent to swine industry stakeholders for review and feedback.

Webtool Promotion

In its final form, the webtool was promoted widely via a range of methods:

1. A set of presentations coordinated with the Prairie Swine Centre's 'spring tour' of producer group meetings in Alberta, Saskatchewan, and Manitoba (April, 2019, see details in Appendix 2)

2. Distribution of a printed webtool promotion card at producer meetings and agricultural health and safety events

3. Publishing an article in the newsletter of the Prairie Swine Centre and the Agricultural Health and Safety Network (see appendix 5 for a copy of the article)

Figure 12: Abisola Omoniyi delivers a presentation on the project and the webtool at a pork producer meeting coordinated by the Prairie Swine Centre in April 2019

4. Promoting the webtool via social media channels (i.e. twitter and facebook). These messages were shared with partners (e.g. WCB Manitoba, SafeWork Manitoba, the Manitoba Pork Council, Saskatchewan Pork Development Board, and Prairie Swine Centre) to encourage promotion to the widest group of target users. Sample social media messages are found in appendix 6.

5. Detailed documentation of the web content accompanies this report (see appendix 4) for the WCB Manitoba archive.

Figure 13: Promotional card promoting the webtool that was distributed to producers. Front side at left, back side at right.

Conclusions and Recommendations

Recommendations for industry

This multi-dimensional study addressed a consistent decision facing producers: is it desirable to implement new technology in their operation? As well as investigating the economics of this decision, it endeavoured to provide a means to investigate health and safety impacts resulting from agricultural industrialization. This study also addressed the widespread but understudied issue of 'unintended consequences' in ergonomic interventions, whereby an intervention intended to reduce or eliminate one risk can end up introducing another. Despite our hypotheses that needle-less injection would introduce new hazards, this study demonstrated that the implementation of new technology in the swine industry can be accomplished without negatively impacting the health and safety of workers. In fact, as was found with the needle-less injector, new technology may even reduce exposures to risk factors (as demonstrated by decreased muscle forces and movement speeds during barn measurements) and reduce rates for at least some types of injury (as was found via decreased WCB claims rates for needle-sticks). These occupational health and safety benefits were accomplished with a concurrent increase in productivity that resulted in an overall long-term profitability, despite the substantial capital investment involved in implementing a new technology.

These key findings are unique to needle-less injection, however, the project also developed a web-based decision making tool that will help producers identify the costs and benefits of new technology, with a particular focus on occupational health safety impacts.

Process recommendations for researchers and practitioners

1. It is very useful to recruit a group of relevant stakeholders to advise on the project, and include them from the beginning. This does take a little more time (see below), but it is worth it for the improvements it delivers to the findings.
2. Do not underestimate the amount of time required for Stakeholder advisory group consultation, and the amount of rejigging required when they provide feedback
3. Comprehensive evaluation is multidisciplinary, and will require contributions from multiple people with various expertise. Allow time for learning one another's vocabulary and methods, so as to understand how they integrate into the findings as a whole.
4. Earmark a substantial portion of the budget for KTE, it is a vital investment in promoting uptake of best practices.

Appendix 1: Terms of reference for the Stakeholder Advisory Group

Overall Purpose of the Study

Over the past several years, Canadian pork production has moved from smaller family farms into large-scale, industrialized production; this change has spurred several process changes and technological advancements throughout the Pork Value Chain. Although these innovations may have an impact on worker health and safety, these impacts (whether positive or negative) can be difficult to quantify and integrate with business decisions. This project will develop a suite of performance measures (a 'toolkit') applicable to new workplace technologies. The toolkit will be comprehensive in its assessment, incorporating implementation costs, productivity changes, health and safety impacts, and worker feedback. The Stakeholder Advisory Group goal is to help direct and interpret this research project.

List of Members

Name	Affiliation
Janice Goldsborough	Manitoba Pork Council
Mark Flynn	Manitoba Pork Council
Bobbie-Jo Porter	Personnel Manager, OlySky (Pork Producer), SK &MB
James Battershill	Keystone Agricultural Producers of Manitoba
Chandra Rempel	Keystone Agricultural Producers of Manitoba
Gail Archer-Heese	SAFE Work Manitoba's SAFE Farm Coordinator
Jeff Shaw	SAFE Work Manitoba
Bruce Ceilen	WCB Manitoba
Joanne Machado	WCB Manitoba
Marcel Hacault	Canadian Agricultural Safety Association
Korine Talbot	Veterinarian, Hylife (Pork Producer), MB
Rob Radawetz	Hylife
Paul Schneider	Industry Stakeholder
Ravneet Kaur	Sask Pork
Tatjana Ometlic	Production Worker, Prairie Swine Centre, SK
Bernardo Predicala	Investigator, U of S/Prairie Swine Centre, SK
Lee Whittington	Investigator, U of S/Prairie Swine Centre, SK (now retired)
Brenna Bath	Investigator, U of S, SK
Stephan Milosavjlevic	Investigator, U of S, SK
Catherine Trask	Investigator, U of S, SK
Aaron Kociolek	Investigator, U of S, SK
Abisola Omoniyi	Research Assistant, U of S, SK (no longer a student at U of S)

Former members:

Name	Affiliation
Harvey Wagner	Sask Pork Development Board (now retired)
Muzi Li	Former Research Assistant, U of S, SK (no longer a student at U of S)
Gbenga Adebayo	Former PhD Student, U of S, SK (no longer a student at U of S)
Xiaoke Zeng	Former Research Assistant, U of S, SK (no longer a student at U of S)
Bridget Gray	Sask Pork Development Board

How do Stakeholder Advisory Group Members Contribute?

- The Stakeholder Advisory Group will meet up to 4 times during the 2 years of the grant.
- Members will be polled for availability and invited to meetings at least 1 month in advance to facilitate participation.
- Travel and parking stipends will be available; members can also participate by videoconference or teleconference if they prefer.
- An agenda and any summary materials will be made available a week before the meeting.
- Meetings typically start with a presentation on research progress; members are asked to give feedback on interpretation of results.
- Meetings will also include proposed plans/strategies going forward; members are asked to contribute to research plans with the goal of maximizing utility and applicability of results to the swine industry.
- At the stage of the project when final results are available and members have contributed to interpretation, the group will brainstorm how to disseminate results and deliver decision-making tools to producers.
- Notes from the meeting (including action items), will be summarized and sent out following the meeting for any additional input and kept for researcher's references between meetings.

Appendix 2: List of presentations related to the project

Stakeholder Audiences

1. Abisola Omoniyi (2019): Using the Technology Adoption Decision-making Tool for Swine Operation. Prairie Swine Centre Producer Meeting on April 5, 2019 at Niverville, Manitoba, Canada. (number of attendees: 70)
2. Abisola Omoniyi (2019) Using the Technology Adoption Decision-making Tool for Swine Operation. Prairie Swine Centre Producer Meeting on April 9, 2019 at Strathmore, Alberta, Canada (number of attendees: 83).
3. Abisola Omoniyi (2019) Using the Technology Adoption Decision-making Tool for Swine Operation. Prairie Swine Centre Producer Meeting on April 10, 2019 at Saskatoon, Saskatchewan, Canada (number of attendees: 29).

Scientific Audiences

1. Catherine Trask, Biaka Imeah, Brenna Bath, April Liu, Olugbenga Adebayo, Masud Rana, Bernardo Predicala, Erika Penz, Stephan Milosavljevic, Lee Whittington, Aaron M Kociolek (2018) Whole Hog Research: Ergonomic Evaluation and Cost-Benefit Analysis of Needle-less Injection Tools in Pork Production. Canadian Association for Research on Work and Health Conference. October 21-23, 2018 Vancouver, Canada.
2. Kociolek AM, Trask C, Keir, PJ. (2017) Revisiting models of tendon-joint interaction as a tool to evaluate ergonomic interventions in the workplace: swine injection technologies as a test case. CRE-MSD Research Day hosted by the Department of Kinesiology, Brock University. St Catherines ON, June 16, 2017.
3. Imeah, Biaka, Penz, Erika, Trask, Catherine. (2017) Cost-benefit of needleless injection devices in swine. Saskatchewan Epidemiology Association (SEA) Annual Symposium. Regina, Canada November 2, 2017.
4. Adebayo, O., Kociolek, A., Bath, B., Predicala B., Trask, C. (2016) Patterns of biomechanical distal upper limb exposures in swine farm workers using the needleless injector and conventional injection techniques Saskatchewan Epidemiology Association 16th Annual Fall Symposium, November 2nd, 2016, Saskatoon
5. Adebayo, O., Kociolek, A., Bath, B., Trask, C. (2016) Comparison of biomechanical upper limb exposures for musculoskeletal disorders in swine barns using needle-less and conventional injection techniques. 9th Biennial Conference of the Canadian Association for Research on Work and Health, October 16-18, 2016, Toronto, Canada

Appendix 3: Peer-reviewed scientific articles published to date

1. **Trask, C.**, Bath, B., Milosavljevic, S., Kociolek A..M., Predicala, B., Penz, E., Adebayo, O., Whittington, L. Evaluating swine injection technologies as a workplace musculoskeletal injury intervention: a study protocol. BioMed Research International. Volume 2017, Article ID 5094509, 9 pages https://doi.org/10.1155/2017/5094509

Appendix 4: Content and resources related to the webtool

The webtool is available on the Prairie Swine Centre website: https://www.prairieswine.com/tools/ Accompanying resources will include the code/digital media for the webtool, which are forwarded alongside this report for WCB Manitoba to archive in their resource library.

Appendix 5: Article for producer newsletters

This article was developed for dissemination by the Prairie Swine Centre and the Agricultural Health and Safety Network in their regular newsletters to producer groups.

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Headline: What can the Web Calculator do for me? Applying the Technology Decision Calculator for Swine Operation Profitability

New technologies are constantly being introduced into barns due to promised benefits and enhanced profitability. However, these innovations can also introduce new challenges and costs, such as the impact of new technologies on worker health and safety. So how do you know if it will work in your specific situation? Prairie Swine Centre and the Canadian Centre for Health and Safety in Agriculture have collaborated to develop a simple, personalizable web calculator that can help predict the value of technology adoption. This multidimensional tool incorporates implementation costs, productivity, and health and safety impacts, and was developed to help forecast the overall benefit of investing in new technology.

Visit the technology decision calculator online to see if that new tool, equipment, or process has what it takes to be profitable in your barn. In a few simple steps, you can fill in the inputs and click on the 'calculate' button to get a personalized result presented as incremental cost-benefit ratio. The incremental cost benefit ratio shows the difference between the current situation and what is obtainable with the new technology; values greater than one indicate profitability, while values less than one indicate the proposed technology isn't a good bet. In addition to the incremental cost-benefit ratio for over the life span of the new technology, the printable report delivers a range of estimates based on different pork prices and cost and benefit variance.

The technology decision calculator was developed based on the test case of needle-less injectors, the topic of a research study at the Canadian Centre for Health and Safety in Agriculture. In many cases, it is not possible to know in advance what all the costs will be. Since it is not always possible to get precise costs when estimating the amount of labour, maintenance, and productivity increases, this tool also provides information to allow for educated estimates. We provide background information, things to consider, and the dollar-value results from the needle-less injector study. Of course, each new technology is different, but it is hoped that this background information will allow you to make an educated guess about the numbers for your enterprise.

Of course, all model reports are estimates and not a guarantee. The model cannot account for all possible variables and is only as accurate as the numbers given as inputs. This tool allows you to select the range of certainty for your cost estimates, resulting in a range of potential cost-benefit estimates. The lowest estimates from cost benefit analysis are considered the most conservative, i.e. the worst-case scenario. If the conservative 'worst case scenario' is still profitable, then the model projects that your organization would still benefit from the new technology even with the worst combination of costs and benefits. You can also re-run reports for different values, and see how small differences can add up. We invite you to try using this web calculator for your next project and see how it works.
We would love to hear your feedback!

Access the technology decision tool via the Prairie Swine Centre ‘Tools’ website.
To learn more about the needle-less injector study, visit our study website.
With questions or feedback about the tool, feel free to contact us directly:
Abisola Omoniyi, Study Coordinator (+1306 966 5971, email: abisola.omoniyi@usask.ca)

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Appendix 6: Sample social media messages

Catherine Trask
@ergo_trask

It promises sunshine and rainbows, but will that new technology will work on your farm? We developed a web-based decision calculator with inputs specific to your farm and a personalized report of the bottom line.
https://www.prairieswine.com/tools/
#farmsafety #aghealth #cultivatesafety

Catherine Trask
@ergo_trask

Sometimes the best new thing can cause problems you didn't anticipate. Our new web-based decision calculator estimates the bottom line for new farm technologies… it even accounts for worker health & safety!
https://www.prairieswine.com/tools/
🐷 #farmsafety #aghealth #cultivatesafety

Catherine Trask
@ergo_trask

There are no guarantees in life, but investigation at the outset of a project can help ensure it is safe AND profitable. Our new web-based decision calculator estimates the bottom line for new farm technologies …let us know what you think!
https://www.prairieswine.com/tools/
#farmsafety #agsafety #aghealth #cultivatesafety

Catherine Trask
@ergo_trask

It's good to have help when making a big decision.
The decision calculator can helps include worker turnover, health & safety, and ongoing maintenance costs when deciding how to invest in farm production
YOUTUBE LINK
#farmsafety #agsafety #aghealth #cultivatesafety

Catherine Trask
@ergo_trask

Thinking of investing in something new on the farm?
Make sure it will pay off without introducing new safety issues. Our new web-based decision calculator estimates the bottom line for new farm technologies.
https://www.prairieswine.com/tools/
#farmsafety #agsafety #aghealth #cultivatesafety

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