Final Report

AMPC
AUSTRALIAN MEAT PROCESSOR CORPORATION

Implementing exoskeletons in meat processing

The implementation of cobotics and exoskeletal devices for the Australia red meat processing industry – Phase 1

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1.0 Executive Summary

The implementation of exoskeletal devices for the Australia red meat processing industry – Phase 1.

1.1 Introduction & context

Exoskeletons are human assistance devices that are worn by a person, adjusted for optimal fit and activated to provide posture, movement and force assistance for the targeted parts of a person's body. Mechanical structures and components operate to move and support the targeted part or parts of the wearer's body inherent to the intended design features of the worn device. Exoskeletons currently exist for a wide range of body locations that include the neck, trunk (lower back), shoulders, thumb and fingers and lower limbs (hips and knees). There are even shoe technologies that deliver energy back to a person during movement.

This assistance provided by an exoskeleton can be as simple as holding one or more joints in a fixed position, like a splint, when they experience force exertion against an object (Ottobock Thumb X). They can also be as complex as a worn soft garment, such as a glove, that can accentuate the grip and holding forces of the thumb and fingers, based on the settings of the pressure sensors within the device, and the application of AI that enables the device to learn, adapt, anticipate and then activate grip movement patterns and the levels of force applied to perform manual tasks (Bioservo, Ironhand bionic glove).

The recent and abrupt emergence of Artificial Intelligence (AI) as a disruptive technology that may revolutionize industry practices and efficiency, reflects many years of investment, development, testing and refinement.

There appears to be a similar pathway with the development of current and emerging human assistive devices, such as exoskeletons. These devices, with their origins in the use of mechanical splints and aids (orthotics) to assist humans to overcome disability and limited physical function are undergoing a rapid transformation in the type, capacity and application of assistive mechanisms that are being specifically designed to enhance human capability beyond normal or average levels. Like AI, these technologies may have the capacity to revolutionise how manual work is performed, particularly for industries where there are substantial challenges in mechanising and automating manual processes due to task complexity and specific environmental and compliance requirements. Conditions that prevail within the Australian red meat processing industry.

The emerging availability of exoskeletons and other human assistance technologies, such as cobotics and collaborative robots, has substantial implications for the red meat processing industry that has, and continues to, rely on the sophisticated hand-eye co-ordination and proprioceptive* capabilities of humans, which are normal human attributes.

*(*proprioception = sense of knowing where the hands are within a space without having to look at them to control their movement)*

1.2 Project objectives

To investigate the range and type of exoskeletons devices that may be of use to the Australian red meat processing industry and then establish a platform for the industry to be able to critically evaluate and, where appropriate, implement these devices, the AMPC commissioned this project.

The core objective of this project was to evaluate current and emerging exoskeletal devices for the Australian red meat processing industry to:

1. Ascertain where the solution can be deployed now within the industry.

2. Ascertain where the solution can be deployed now, with minor changes.
3. Ascertain where the solution could be evolved for future deployment.
4. Understand the benefits (if any) that exoskeletal devices can provide to meat processors across a number of tasks in both sheep and beef processing.

1.3 Approach

This project was conducted in 3 distinct stages:

1. Stage 1 – Identification and selection of current and emerging devices.
2. Stage 2 – Laboratory based testing of selected devices.
3. Stage 3 – Site (processor) based testing of selected devices.

Stage 1 of the project began with an initial literature review. Because of the rapid advances in exoskeleton technologies over the past decade orientated toward their use within industry, a lack of high calibre and informative peer review literature was revealed. Of the limited number of papers discovered, they either significantly pre-dated newer technologies or they could not demonstrate sufficient confidence in their ability to anticipate and extrapolate the results into the complex industrial, environmental and regulatory setting of the meat industry. Accordingly, the limited literature review conducted didn't deliver any substantive contribution. Much of the information obtained for reference within this project was grey literature that described, evaluated and promoted devices, without necessarily having a solid evidentiary basis of their medium and long term impact once implemented.

While the literature was being undertaken, a parallel search for current and emerging exoskeleton technologies was conducted. This involved gathering the devices that had already been promoted and provided to the meat industry for review as well as conducting internet searches that eventually focused on review web sites and the sites of device developers and manufacturers.

At the outset of this project, there were no devices manufactured within Australia and only one device had an existing distributor within the country. All devices were sourced from overseas manufacturers and/or distributor. While a number of well-established devices for the back and shoulders were provided by manufacturers based in the United States of America, the newer and emerging devices of most potential relevance to the meat processing industry were located within Japan and Europe.

An open mind on the design and features of devices was maintained to facilitate the potential to discover innovations that may be suitable for, or be adapted to, the meat processing industry. Nineteen devices were selected that covered the back, upper limbs and lower limbs. Other devices, in particular, active or powered devices for the back and shoulders, were located. However, it was either not possible to establish contact with the manufacturer or they could not be convinced to provide their devices into Australia, ahead of any plans to market their product and establish a distribution and support network here.

As the procured devices arrived, the Stage 2 laboratory testing activities were conducted. This largely involved familiarization and practice with each device and its method of adjustment for optimal fit and determining how the assistive features of each device worked. For some devices, measurements of muscle function with and without the device being worn were conducted. These tests were conducted to confirm the broad claims of what the device does to assist the wearer. This information was indicative and useful but did not constitute a formal study of their function.

During this stage, a range of functional, operational and safety criteria considered to be fundamental for use of an exoskeleton with the meat processing industry were established. The criteria were intended to guide the assessment of potential devices and enable those exoskeletons least likely to be useful, or those that may be the most difficult or

complex to incorporate into the complex meat processing environment, to be quickly filtered out and excluded. The ability to clean a device after use was identified as a fundamental industry requirement in exoskeleton design. A device with innovative features may not be usable in this environment if it cannot be adequately cleaned after use. These criteria were developed at each stage of the project and have been consolidated into a 5-step guideline for the evaluation and implementation of exoskeletons for the red meat processing industry (see Appendix 9.1).

Stage 3 of this project commenced with the selection of those devices found to be most suitable to the broad needs of the meat industry. The full list of devices is described below. Those devices selected for in-processor trials have been bolded.

Trunk - Back

1. Hal-LB01, by Cyberdyne
2. Japet (corset), by Japet
3. **Apex, by Herowear**
4. **Bionic Back, by hTRIUS**
5. **Hapo Back, by Ergosante**
6. Back X, by Suit X/Ottobock
7. **Laevo Flex, by Laevo**
8. Laevo 2.57, by Laevo
9. Paxeo Back, by Ottobock

Trunk - Neck

10. Paxeo Neck, by Ottobock

Upper limbs – Shoulders

11. **Hapo Front (was MS), by Ergosante**
12. Evo Vest, by Ekso Bionics
13. **Paxeo Shoulder, by Ottobock**
14. Exo-01, by Hilti (rebranded Ottobock Paxeo Shoulder)
15. Shoulder X, by Suit X/Ottobock

Upper limbs – Hands and Fingers

16. **Ironhand, by Bioservo**
17. **Paxeo Thumb, by Ottobock**

Lower limbs – Hips and Knees

18. Leg X, by Suit X/Ottobock
19. Chairless chair, by Noonee

Of the eight shortlisted devices, the Bioservo Ironhand glove was identified as the device most likely to have the greatest impact across the broadest range and number of meat processing jobs when compared to the other devices. This powered glove reduces grip forces to grasp and manipulate tools, objects and parts of a carcase being processed. Because of the high level of likely application within meat processing, the Ironhand glove was prioritised for processor-based testing.

Different methods of protecting the selected devices were developed, as much as possible using conventional personal protective clothing (PPC) likely to be available within a processor. Plastic smocks were procured to protect back and shoulder exoskeletons during testing if local PPC items were found to not provide sufficient cover.

Four meat processors were approached to participate in testing. Two sheep processing facilities and two beef plants. Testing was conducted at the two beef plants only. One was in country Victoria and the other in Queensland. These tests focused on the use and evaluation of the Ironhand glove within production (slaughter) and processing (boning and slicing) areas. The design and function of the other selected devices were presented and discussed during these site visits.

1.4 Project outcomes & insights to benefit AMPC members & the industry

This primary outcome of this project was the identification of devices that are suited for short to medium term use within meat processing facilities in Australia. It is not possible to predict likely long-term use of any device within this industry as there are too many unknown factors. These devices most suited to short to medium term use include the powered glove, several trunk and shoulder devices, and thumb splints (see Section 1.3 above). The devices not recommended for implementation were found to be effective and functional as exoskeletons and the main reasons for their exclusion at this time is the complexity of cleaning them after daily use.

The project delivered an additional range of diverse outcomes that went beyond the selection of exoskeletons for implementation. These additional outcomes include the identification of a broader range of strategies that might steer the industry to get best use of assistive devices for jobs that require this assistance as well as increasing the use of data gathering within exoskeletons so they can establish a pathway to better inform how increased mechanisation and eventual automation, or semi-automation of industry jobs may occur.

The following outcomes were achieved within this project:

1. Literature review.
2. A simple categorization method for exoskeletons to understand their core attributes relative to the meat processing environment.
3. Selection and procurement of 19 exoskeletons for evaluation.
4. Exoskeleton evaluation outcomes.
5. Development of a step-by-step process to guide meat processors in the evaluation and implementation of exoskeletons and other human assistance technologies such as cobotic devices and collaborative robots.
6. Development of a state of knowledge regarding the rapidly emerging exoskeleton industry, innovative devices being developed and the opportunities that exist for the Australian red meat processing industry.
7. Identification of the benefits of defining the nature of meat processing jobs and tasks to drive the development of exoskeletons and other human assistance technologies.

1.5 Conclusions & recommendations for further research/actions

The primary conclusion of this project is the confirmation that exoskeletons and other human assistance technologies have great potential to be useful in not only reducing the physical demands of many manual tasks performed within the industry and possibly improve the physical efficiency of operators, but how they may be used to better understand the nature of production and processing tasks and accelerate the development of greater mechanisation and automation across the industry. This active engagement of the industry with these technologies is compelling.

However, the functions of these technologies need to be balanced with the ability to incorporate these devices into the day-to-day requirements of the industry for meat safety, wearer safety, operator and product hygiene, maintenance of product quality and production efficiency. A range of devices assessed within this project have been recommended for prompt implementation.

Secondarily, the co-ordination of the exploration of and engagement with these technologies could be maximised by the development and resourcing of a specialist group within the industry. This group could be part of an AMPC initiative and could steer the direction of greater engagement with relevant and useful technologies, which could include working with developers of these technologies to better accommodate meat processing industry requirements.

In summary, the key recommendation of this project is to convene a specialist industry reference group to focus on human assistance technologies to create the framework to co-ordinate and oversea the next steps in the greater engagement with current and emerging technologies for the Australian red meat processing industry. The group could be formed under the AMPC research and development umbrella and be established as an industry project.

The recommended main functions and approaches of this reference group are:

1. Convene the reference group within an AMPC project to represent industry stakeholders. Establish the objectives, operational parameters and budget for this group.
2. Establish a road map to define the pathway for the acceleration of the initial implementation of exoskeletons found to be of likely use for the industry within this project as well as the broader exploration, development and uptake of other human assistance technologies that will provide optimal benefit for the industry. The short-term goals of this initiative should be to enhance the work capability of employees within meat processors, while the long-term goals should be to influence greater mechanisation and process automation by utilising advanced technologies and learning from any data generated and the experience of their application and use.
3. Develop a standardized job assessment format that defines the physical work tasks performed within the industry . This reference should describe the summary features of the postures, movements, forces exerted and duration and frequency of meat production, processing and ancillary jobs. This will provide a foundational reference for the consideration and matching of human assistance technologies and is likely to support the early identification of opportunities for enhanced mechanisation and automation.
4. Develop global relationships with technology developers and form active relationships with those that have devices most pertinent to the meat processing industry. These relationships should be based on communicating the needs of the industry with these technologies and working with them to achieve designs that work within this environment.
5. Develop a media platform for this industry reference group to communicate its activities, messages and outcomes as a means of supporting the education of the industry about human assistance technologies for the industry.
6. Adopt the 5-step guideline developed within this project to standardize and support the short-term implementation of exoskeletons. This guideline outlines methods to evaluate prospective exoskeletons and support the implementation of devices found to have the greatest potential to assist the industry.
7. Implement the exoskeletons found to be suitable for prompt use across the industry. Use Step-5 of the guidelines to steer this process.

2.0 Introduction

2.1 About this project

With the arrival and rapid emergence of exoskeletons as a possible tool to enhance worker physical capacity, AMPC sought to not only objectively investigate the suitability of exoskeleton devices being introduced in Australia, but to conduct a global search of current and emerging technologies that may be relevant to the meat processing industry.

This approach would enable the discovery of technologies regardless of their stage of development and commercial release. With this project, AMPC determined to “get ahead of the pack” by not only evaluating currently available devices, but to discover new and emerging devices with potential benefit to the industry. Within this process it was anticipated that a range of evaluation criteria to support the rapid and objective evaluation of devices could be developed as devices are introduced into Australia, In addition, strategies for the implementation of exoskeletons, and other human assistance devices, to optimise their efficient and effective uptake within the meat processing industry could also be developed.

In summary, this project was constructed to accelerate the meat processing industry’s state of knowledge of exoskeleton devices to enable it to be able to objectively select, evaluate and implement the devices that are most likely to provide benefit for the industry.

Because of the relatively new field of commercially available exoskeletons, and the paucity of academic research on exoskeletons, this project took a “green field” approach where an open-minded process of discovery was taken to avoid any bias and the risk of “missing” a new or emerging device. This approach was rewarded with the discovery of the Bioservo Ironhand glove – a bionic glove that has the potential to reduce the physical demands of grasping tools, objects and parts of a carcase for employees across the entire red meat processing industry in Australia.

This project was conducted by the report author, Chris Fitzgerald, Certified Professional Ergonomist with Risk and Injury Management Services, a specialist OHS and Ergonomics consultancy based in Melbourne, Victoria. Initially it was anticipated that approximately 12 devices would be procured for testing. As the search progressed 19 devices were identified as being relevant and were procured for testing.

2.2 Background

Since its inception, the Australian Red Meat Processing industry has, and continues to, rely heavily on the performance of manual tasks by employees at all stages of stock preparation, production, processing, packaging and dispatch of meat products. The development of innovations in reducing greater mechanisation and automation have been continually supported by the industry over the past 3 decades. However, while the pace and reach of such innovations appear to be accelerating, their impact to date in replacing or diminishing manual work tasks at any substantial scale remains limited.

The biggest challenge to greater mechanisation and automation in this industry is the inherently complex nature of the manual tasks that need to be performed to remove the skin and viscera of cattle and sheep to produce carcases and then break these down into red meat products. However, there is a highly compelling demand to create innovative improvements in meat processing methods because of the:

1. Often remote location of processing facilities where access to labour is limited.
2. General scarcity of skilled labour that is prepared to work in meat processing facilities and the need to be able to welcome a very broad range of potential employees to perform this work.
3. Resulting increase in workforce recruitment from other regions such as, Asia, Africa, Middle East and Pacific Islands, that have increased the diversity of body sizes and strength capabilities of the red meat industry work population.
4. Costs of supporting skill acquisition and maintenance of the work force.
5. Variation in body size and shape that occurs within species that increases the complexity of the design and adoption of consistently effective automated processing methods to ensure that the highest yield and product quality possible is maintained.

6. Inherently dexterous and physically demanding nature of the work performed that must be replicated by these automated processing methods.

Regarding the physical demands of meat processing, this type of work requires people to consistently perform manual tasks over a shift that can utilise:

1. Sustained and/or awkward postures.
2. Repetitive movements that may at times be awkward or exceed a low range of joint movement, in particular movements of the hands/wrists, shoulders and back.
3. The frequent exertion of awkward and/or moderate to high forces to grip tools and parts of a carcase or packaged products to process and handle them.
4. Limited variation from these physical demands, resulting in higher than preferred exposures to the physical demands of red meat processing work.

While the industry continually seeks to develop design led improvements to reduce or eliminate these physical demands for employees, replicating human hand-eye co-ordination and rapid task performance decision making with mechanical devices is complex. Without avoiding processor obligations to provide and maintain a healthy and safe workplace, it is increasingly compelling to consider the use of any human assistance devices to reduce these work demands. Exoskeletons are one such group of devices that should be considered.

2.3 About exoskeletons & other human assistance devices

Exoskeletons for industrial use have evolved from orthotic treatment devices that have been to enhance the function of a person with some form of disability or limited physical capacity. Typically, these orthotic devices have been developed as part of a person's neurological or orthopaedic rehabilitation. The early adaptation of these treatment devices from a reactive or rehabilitation perspective to a proactive device to enhance ability, rather than overcome disability, initially occurred in military research. This involved the development of an external structure around a soldier's trunk and legs to divert weight away from their back and upper limbs to their hips and to the ground via these components. The intent was to reduce the effort exerted by soldiers to carry all their required equipment.

More recently, exoskeletons have been developed for industrial use, and numerous devices appear to have been developed within the automotive industry, where a "clean" and well controlled environment can be maintained. Over the past decade, these has been a rapid expansion in the range of developers and devices available, where the predominant target for new and emerging exoskeletons is for use within work settings.

The red meat processing industry continuously drives the general development and adaptation of innovative technologies to make meat processing work safer and less physically demanding. However, only a limited range of strategies in recent times have been oriented towards enhancing the capabilities of employees to perform the inherent physical requirements of specific jobs. One obvious example being the use of meat pulling devices that exert all, or a proportion, of the forces that need to be exerted when boning beef hindquarters.

The recent explosion of Artificial Intelligence (AI) and its emerging impact on the administrative and cognitive elements of work provides a stark contrast to the relatively slow pace of change in the development of innovations and smart methods of performing physical tasks to replace or supplement human work performance. While this reflects the complexity, not only of the manual work performed within meat processing, but also the environment in which this work is performed where must satisfy highly specific requirements for hygiene, productivity and product quality and security.

With this in mind, it is compelling to consider the assistance in the performance of manual tasks that may be provided by the rapid emergence of industrial physical assistance devices for humans, such as exoskeletons, cobotic devices and collaborative robots.

Exoskeletons are devices that are worn by people to provide them with mechanical assistance with the movement of one or more joints of their body. This assistance ranges from helping a person to maintain a posture within a specified range by supporting a proportion of the weight of the part of their body being assisted, to actively providing force assistance to help them move that part of their body, reducing the level of effort that they exert to perform the movement. Increasingly, exoskeletons that use a power source to provide active assistance, as well as sensors to help control the movement of the device, are now quantifying how the device is used within a work setting to perform specific jobs and tasks. This measurement feature substantially extends the value of such devices where they can also function as an assessment tool which can help processors to better understand the nature of the work being performed. This in turn can lead to further improvements in work methods and the understanding of the functions within a job that specific technologies will need to be able to perform to support greater mechanisation or automation.

Herowear Apex

hTRIUS Bionicback

Laevo 2.57

Laevo Flex

Images 1, 2, 3 & 4 – Passive back exoskeletons

Cobotic devices are devices that are not worn by a person but can be used by them to assist with one or more aspects of their work. Cobotic devices include meat pulling chains or levers that exerts or helps exert the force needed to pull cuts of meat from bone during boning. These types of cobotic devices, such as beef hind quarter pullers, have been used with good effect in the Australian Red Meat Processing industry for several decades. Other less acknowledged cobotic devices include tool support or assist devices such as spring balanced overhead cables that partially support the weight of a tool that is used within the production process. Examples of these are cables that support brisket shears, head removal shears and brisket rollers in sheep production and the carcase splitting saw that is used in beef production.

Collaborative robots are operational robots that can independently perform one or more components of the full range of jobs and tasks that are usually performed by people. For example, in some food agricultural processes, an automated trolley can be used to transport picked produce from the harvesting location to the next phase of processing. When these devices perform one or several parts of a worker's range of work tasks, it frees them up to focus on those elements of the work that specifically rely on their skills to perform, often producing a notable productivity gain.

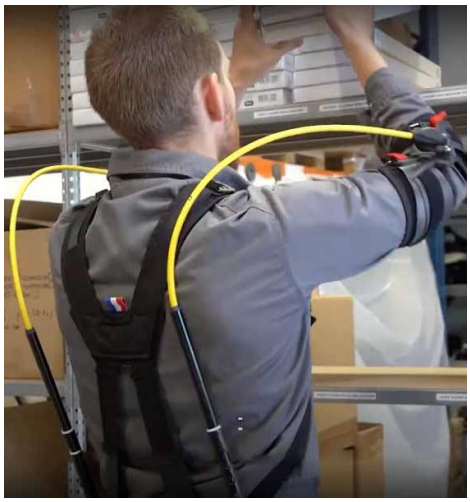
Within the Australian Red Meat Processing industry, the uptake and use of exoskeletons is likely to be an interim approach to support the short to medium term reduction in physical work demands for employees, or more correctly, to enhance the capacity of employees to perform physically demanding work jobs and tasks. This anticipated use of exoskeletons highlights the need to not ignore the inherent design of work process and jobs, how they contribute to physical work demands and whether design improvements should be the priority to reduce these demands to achieve a better match between these demands and the capabilities of the work force. That is, the use of exoskeletons as a sole or long-term strategy may not be sufficient to achieve a durable and long reduction in physical work demands for employees.

Longer-term solutions for the design of work within this industry are likely to rely on the greater mechanisation and automation of meat processing tasks as well as the greater uptake of cobotic devices and collaborative robots.

2.4 How exoskeletons work

Exoskeletons are devices worn by a person that exert force over one or more joints of the human body to assist them to undertake certain movements and/or adopt specific postures. The devices typically do not provide the movement for the person, but rather they assist and enhance the movements the person makes or help them to sustain a posture within a pre-determine range. The level of assistance provided by a device depends on the design of its assistive mechanisms, how it is powered and the level of adjustment available and set by the wearer.

Exoskeleton devices are now available that cover the whole body that includes the upper and lower limbs and the upper and lower back. Even footwear devices are now available, or in development, where ground reaction energy is provided back to the foot to assist and enhance movement and capacity.



Ergosante Hapo Front

Hilti Exo01/Ottobock shoulder

Images 5 & 6 Passive shoulder exoskeletons

Suit X Leg X (active)

Ottobock Paxeo neck (passive)

Ottobock Paxeo thumb (passive)

Images 7, 8 & 9 Leg, neck and thumb exoskeletons

Exoskeletons can be categorised according to the nature of their power source and how energy from that source is delivered to the device's movement mechanisms. These categories are active or passive.

1. **Active exoskeletons** have an external power source, typically electronic, that is supplied by one or more batteries. The device can provide its assistive functions while there is sufficient charge within the battery.
2. **Passive exoskeletons** use levers, springs, elastic chords or rubber straps to absorb energy when the person moves the supported joints away from a neutral position. These passive devices either hold this tension to help maintain a posture within the range provided by the device, or they give this energy back though the device to assist the wearer to move the body part(s) covered. Often these assistive movements of the exoskeleton occur at the start of a movement, where effort to generate the movement can be greatest. Some devices provide a support in a single fixed position (Paxeo Neck and Thumb). While these devices provide static support, they have been included within the passive classification as this is consistent with their means of delivering this assistance.

To be able to exert sufficient force to help move or hold one or more joints, the worn device must be anchored onto the person's body, above and below these joints. When the device is anchored, the force exerted by the assistance mechanism is transferred to the joints covered. If an exoskeleton is not suitably anchored onto the wearer's body, the device itself will move and not translate any, or only insufficient, force to the user. This type of poor fitting may also be hazardous for the wearer.

Given the importance of good fit on how the device functions, the ability to select the appropriate size for a person and then adjust the fit of the device for optimal comfort and function, is a basic, but critical design feature and criterion for selection. Of the devices chosen for this project, one device, the active/rigid HAL-LB03 low back exoskeleton by Cyberdyne did not have the capacity to adjust the width of its fitting, having been initially designed for the Japanese population as a treatment device and then it's used being expanded into workplace settings. Full assessment of this device did not proceed, in part on the basis that it was not likely to be able to fit a large section of the potential user population in meat processing facilities. This feedback was provided to the Australian distributor and the most recent version of this device has now apparently included capability to adjust its width across a person's hips to then accommodate a broader proportion of potential wearers.

The level of assistance provided by a device will mostly depend on the nominated setting, provided these are available. Part of the evaluation of an exoskeleton should be on the range of support or assistance that the device provides, relative to the tasks being performed. It will be difficult to evaluate the level of assistance provided by simply looking at the device and testing it outside of a work setting. Instead, a workplace trial and feedback from those wearing it will be required to assess these features.

All devices found within this project, except one, use the good fit of the device onto the wearer's body, in combination with a nominated activation setting level and, for some devices, the range of movement over which this assistance is delivered to configure the assistance of the device. Mostly, the wearer would progressively make these adjustments, starting at a conservative level and adjusting "upwards" and fine tuning the adjustment at their upper preferred level to achieve their optimal setting. This fine tuning requires the wearer to establish an assistance level and movement range that suits them and the postures, movements and forces they use to perform the job and its component tasks.

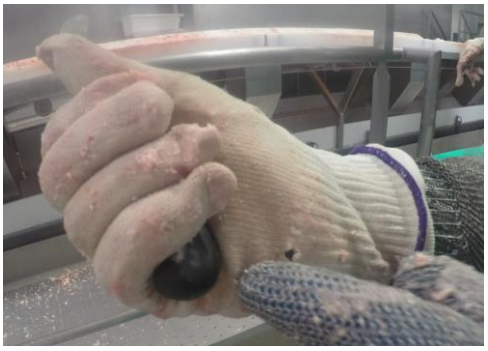
However, the provision of a fixed level of assistance according to these adjustments, can be inherently limiting as the setting may not reflect the dynamic nature of the job. For short duration jobs with a similar range and type of postures and movements, which are common in meat processing, this may be suitable. For more dynamic and physically variable work however, a lower fixed level of assistance may be established to deliver an "average" level of assistance where it is not excessive for any task but provides some assistance for most or all tasks.

This short job cycle and limited physical variation within jobs, which is a common design feature of meat processing work, is one factor that indicates a likely suitability of using exoskeletons to enhance the physical capacity of employees performing this work.

One device used a very different approach to delivering force assistance to the wearer's body with a device that covers the 15 joints of the thumb and fingers. This device is the Ironhand bionic glove by Bioservo (Sweden) and was found to be the most sophisticated device found within this project. The Ironhand glove not only uses pressure (force) sensors in the palm, thumb and fingers to activate the controls over each digit, but it has incorporated Artificial Intelligence (AI) into the mechanism, so the device learns about and responds to the movement patterns of the wearer while they perform their work. That is, the device provides dynamic levels of assistance within the scope of the core thumb and finger activation settings and the overall "volume" (how much force exerted) setting of the whole glove.

Ironhand glove (soft/active) and bodypack when fitted

Images 10 & 11 – Bioservo Ironhand



Ironhand glove when fitted and protected in a boning room

Images 11 & 12 – Bioservo Ironhand

Because these sensors are gathering and responding to forces exerted against the glove, the computer application for this device is able to receive, analyse and present data back that explain the patterns of use of the glove in a raw from as well as in a processed form where the data is expressed relative to likely injury risk exposures.

In addition, during this AMPC project, it was determined, while working with the developer of this technology, that this glove can be used as an assessment tool for force exertion, providing calibration force values are obtained as part of the usual calibration process that occurs at the start of a wearer's session of using the glove.

This approach was regarded to be revolutionary and demonstrated the likely direction that manufacturers may pursue to add value to their devices and provide methods of providing quantitative feedback and validating the function of the device directly with those purchasing and using it. Given the inherently manual nature of meat processing work, the uptake of the Ironhand glove within the industry is compelling and presents an untapped opportunity to enhance work capacity broadly across the industry.

Based on this high level of functionality and usefulness presented with the Ironhand glove, it is likely that other exoskeletons will begin to incorporate movement and/or force sensors to improve the sophistication of their devices while providing invaluable data on patterns of movement and general use.

In addition to the method of energy storage and transfer provided within exoskeletons, this project found that there is a second device category relevant to the meat processing industry. This category describes the main structural features of an exoskeleton and whether these are predominantly:

1. **Soft or flexible** – where there are no or only minimal rigid components.
2. **Rigid** – where the only soft components would be any straps to hold the device in place on the person's body and any padding that would be used to distribute of load (force) over a larger surface area, and avoid excessive localised pressure, where force is applied to the wearer's body.

The main relevance of this category to meat processing is the likelihood that exoskeletons with predominantly rigid components are going to more difficult to clean on a daily basis to the level required within this environment. This difficulty in maintaining them may be sufficient to prevent them from being used in some areas within a meat processing plant. Conversely, devices that mostly have soft for flexible components are more likely to be machine washable, where the entire device, or most of it, can be washed with any other non-fabric components being disconnected so they can be wiped clean.

3.0 Project Objectives

As reflected in the title, the focus of this project was on the discovery and implementation of suitable exoskeleton devices into the Australian Red Meat Processing industry. The core objective of this project was to evaluate current and emerging exoskeletal devices to:

1. Ascertain where the solution can be deployed now within the industry.
2. Ascertain where the solution can be deployed now, with minor changes.
3. Ascertain where the solution could be evolved for future deployment.
4. Understand the benefits (if any) that exoskeletal devices provide to operators across a number of tasks in both sheep and beef processing.

How this objective and these elements were achieved across these 4 elements of this sole objective has been described below in this report in Section 5 Project Outcomes. However, a range of additional outcomes were also achieved within this project that went beyond the defined project objective that are important to include in this report. This is because these additional findings provide a perspective on the specific needs of the red meat processing industry that must be satisfied for exoskeleton devices to even be considered for use. A key project recommendation is for the industry to develop a focus and allocate resources for the ongoing engagement with manufactures globally in the development of human assistive technologies that can not only assist, but potentially revolutionise how work is performed within the industry.

4.0 Project Method

This project was conducted in three distinct stages:

1. Stage 1 – Identification, selection and purchase of current and emerging exoskeleton devices.
2. Stage 2 – Laboratory based testing of the selected devices.
3. Stage 3 – Site based testing of devices found to be most suitable.

4.1 Stage 1 - Identification & selection of current & emerging devices

4.1.1 Literature review

The literature review commenced with a search for peer reviewed papers on exoskeletons conducted within the past 10 years. A number of papers beyond this period were sourced but not found to be useful as they were outdated, having been superseded over time and with substantial advances in concepts and technologies.

Only a small number of relevant papers were identified. As contact with different manufacturers was made, they were asked to provide any supporting studies for their devices. Where available these were provided and included within the project. However, a number of these studies had not been peer review or published and were regarded to be contracted assessment studies. While they were reviewed to understand the study methods, data gathered and analyses used, the results were not formally included in this project.

A search of the grey literature was also conducted at this time. A key source of information within this category was the marketing material for the different manufacturers as this was often the only source of information available about a specific device. This reflected the nature of this industry globally where the emergence of new concepts and approaches in providing physical assistance for people with no disability or physical limitations has accelerated over

the past 5 years at a pace that is well ahead of the studies and science that can provide validation or discreditation of the claims of the developers.

One particularly helpful reference was a website that provides critical reviews of devices as they are released or updated. This website is “exoskeletonreport.com” and it provided invaluable information on devices that were still in development or only just emerging as being commercially available in limited locations globally. A number of purchases of devices for this project were mostly based on the reviews provided by this website.

The limited outcomes of the literature review are described below in “Section 5 Outcomes” of this report. A bibliography of the references found is provided in “Section 8 Bibliography” of this report.

4.1.2 Identification & procurement of exoskeleton devices

At the commencement of this project, AMPC had been provided with three exoskeletons from United States of America based manufacturers of shoulder exoskeletons. These were the first devices reviewed and are:

1. Paxeo shoulder, by Ottobock.
2. Shoulder X, by Suit X.
3. Evo Vest by Ekso Bionics.

(Note: since the commencement of this project, Ottobock and Shoulder X have merged).

The search for exoskeleton devices commenced with approaches to these manufacturers to see if they had other available products that may be suitable within the meat processing industry. This resulted in Ottobock providing three other devices, Paxeo Back, Paxeo Neck and Paxeo Thumb. Suit X provided an additional two devices, Back X and Leg X. This resulted in an initial total of eight devices becoming available for testing, with an initial intention of procuring approximately 12 devices for evaluation.

Parallel to obtaining these devices and the literature review (Section 4.1.1 above), an internet search to discover and learn about other available exoskeleton devices was conducted. This search was initiated using key word searches. This revealed a wide range of devices that had either been available for several years as well as the emergence of new devices that were becoming available for purchase. No devices originating from, or manufactured within, Australia were found during this search.

This search progressively revealed devices to assist the back, shoulder, hands and fingers and lower limbs. Devices were reviewed online and, for devices found to be potentially suitable within the meat processing industry, the manufacturers/distributors were contacted. All except one device required contact with organisations based in the Northern Hemisphere (Europe, Japan and USA). The results of reaching out to these groups was very mixed. If there was no response after 3 contact attempts, that device was not pursued any further. This resulted in some interesting devices not being procured for testing. In particular, the range of active devices to assist back and shoulder postures and movements were under-represented in this project and further investigation of these options may be warranted. AMPC may choose to follow up with these organisations in the near future to check any advances of these devices and whether there may be benefits in assessing and trialling them.

Where the manufacturers responded to requests for further information and contact, online meetings were conducted. During these meetings the nature of the red meat processing industry was explained, and participants demonstrated their devices and provided information to assist their initial evaluation. For devices that appeared to be most suitable for the industry, or those that represented lateral approaches to delivering assistance for device wearers, further contact occurred until a decision whether to purchase a device or not was made. Part of this consideration was the capacity of the developer to support their device in Australia beyond this evaluation project.

These considerations have been incorporated into Step 1 of the 5-step exoskeleton evaluation and implementation guidelines that have been developed as a key outcome of this project.

The procurement process went for much longer than anticipated, due to the residue of the Covid 19 pandemic and supply and importation issues. The final devices were received approximately 12 months after the search was initiated.

Also, during this period, additional devices not included in the initial group of devices selected, were included as they had become available within Australia through a local distributor.

The final result was the procurement of 19 devices for testing. Of this number:

1. 9 devices provided back assistance.
2. 1 device provided neck support in an extension posture.
3. 5 devices provided shoulder assistance.
4. 1 device provided thumb support.
5. 1 glove device provided assistance for all fingers and the thumb.
6. 2 devices provided support for the lower limbs in a semi-sitting or deeper squatting posture.

Within this group of exoskeletons, there was a spread of active and passive devices and as well as those with predominantly rigid support and assistance structures or those that most used soft or flexible components. Of the devices obtained, approximately 50% were from USA and 50% from Europe and Japan.

4.1.3 Devices selected & procured for this project

4.1.3.1 List of devices

The result of this process of discovery a total of 19 exoskeleton devices being procured for testing. The names, manufacturer and broad categorisation of these devices are:

Trunk - Back

1. Hal-LB01, by Cyberdyne (active / rigid).
2. Japet (corset), by Japet (active / rigid).
3. Apex, by Herowear (passive / soft).
4. Bionic Back, by hTRIUS (passive / soft).
5. Hapo Back, by Ergosante (passive / soft).
6. Back X, by Suit X/Ottobock (passive / rigid).
7. Laevo Flex, by Laevo (active / rigid).
8. Laevo 2.57, by Laevo (passive / rigid).
9. Paxeo Back, by Ottobock (passive / rigid).

Trunk - Neck

10. Paxeo Neck, by Ottobock (passive / rigid).

Upper limbs – Shoulders

11. Hapo Front (was MS), by Ergosante (passive / soft).
12. Evo Vest, by Ekso Bionics (passive / rigid).

13. Paxeo Shoulder, by Ottobock (passive / rigid).
14. Exo-01, by Hilti (rebranded Ottobock Paxeo Shoulder) (passive / rigid).
15. Shoulder X, by Suit X/Ottobock (passive / rigid).

Upper limbs – Hands and Fingers

16. Ironhand, by Bioservo (active / soft).
17. Paxeo Thumb, by Ottobock (passive / rigid).

Lower limbs – Hips and Knees

18. Leg X, by Suit X/Ottobock (active / rigid).
19. Chairless chair, by Noonee (passive / rigid).

4.1.3.2 Summary description of selected devices

A summary of the key features and functions of each device is described below. A more detailed assessment against the selection and evaluation criteria developed during this project is provided in Appendix 9.2 below.

Trunk - Back

1. **Hal-LB01, by Cyberdyne (active / rigid)**
   This is an active rigid device that is fitted around the wearer's pelvis. Its activation provides assistance for forward and rearward low back movements. It is primarily used to assist patients with neurological condition to support their trunk movement.
2. **Japet (corset), by Japet (active / rigid)**
   This active device is a rigid corset that fits firmly over the outer boney crests of the wearer's pelvis and underneath their ribcage on each side of their body. There are 4 actuators that push the anchored sections of the corset upwards, 2 on each side at the front and 2 at the rear. There are 5 activation level settings that create the upward pushing movement for each of the actuators. Their activation creates a traction effect on the wearer's lower spine while the person is upright. It also limits their capacity to flex their lumbar spine for forward and lower reaching tasks, where the wearer needs to use greater hip and knee flexion to replace this limited low back movement.
3. **Apex, by Herowear (passive / soft)**
   This is a passive and soft exoskeleton device. It is secured to the wearer's torso via a soft harness that extends around the wearer's shoulders and pelvic. There are a range of different sizes or lengths of flat rubber straps. These provide the required energy and are activated when the wearer moves into a flexed trunk position. Different sized straps must be selected and fitted to match the body height and back length of the wearer. These straps are anchored from the wearer's lower back to straps around their thighs. As the person leans or bend forward, the straps are elongated and put under tension or "energised." Apart from selecting the correct strap size as the main form of activation adjustment, this device has an adjustment feature where the wearer can activate a switch that is mounted on the left chest strap to lock and hold the tension of the strap in that selected position. With the position locked in place, the device can help the wearer to maintain that inclined posture, because of the tension that is applied to the strap, or the energy absorption in the strap increases when the wearer moves further forward, providing them with a "kick" when

they initiate the extension movement to reassume an upright posture. The locking device can be easily disengaged to release the tension on the strap and allow it to be reset for the next position. The wearer is able to walk when there is no tension applied to the rubber thigh straps.

4. **Bionic Back, by hTRIUS (passive / soft)**

   This is another passive and soft exoskeleton to assist back inclination and extension movements. It uses a soft backpack style harness that extend around the wearer's shoulders and pelvic. The support straps are anchored around the wearer's thighs, like the Herowear Apex device. The level of tension and assistance provided is adjusted by pulling on 2 tabs located at the wearer's hips. The further these tabs are pulled forward, the greater the "loaded" tension that is applied to the device. These levels of resistance to trunk forward inclination provide support for the adoption of a flexed trunk posture, according to the chosen setting. This tension can be quickly released by "flicking" a small plastic clamp on each strap to the open position, providing readily accessible and usable methods of increasing and reducing this tension and level of device activation. Releasing this tension is done to enable the wearer to walk without restricting their movement.

5. **Hapo Back, by Ergosante (passive / soft)**

   This is third and final passive and soft back exoskeleton. The core design uses a soft harness that is secured around the wearer's shoulders, pelvis and thighs. This innovative device uses flexible fibreglass rods on each side of the wearers body, that extend up from the anchor straps around the thigh, through a restraining loop at the hips, up to the lower section of the chest/shoulder strap. When the wearer moves to a forward inclined trunk posture, tension is applied to the rod to assist them to maintain a static flexed posture and to provide a movement "kick" when the wearer starts to move back to the upright position. The level of tension on the rod, and therefore the level of assistance provided, is adjusted by pulling on the loop strap at the wearer's hips. Pulling this strap moves the rod further forward increasing tension within it when the wearer's torso bends forward. To enable the wearer to walk, brackets within the rods at hip level are released and "break" the rod. With this broken, the rods above and below this point move freely without applying any tension at the shoulder and thigh anchor points. The wearer is then free to walk and move about with no restrictions. Once the wearer is ready to activate the device again, they simply adopt an upright posture and lower the brackets down and along the rod to reform its solid continuous length. During the project two different versions were provided. The older version initially provided used inflatable chest/shoulder supports as a method of distributing load over a broad surface area. The updated version replaced these with soft chest/shoulder pads that were consistent with those used on other soft back exoskeleton devices.

6. **Back X, by Suit X/Ottobock (passive / rigid)**

   The Back X device is a passive and rigid back exoskeleton. The device anchors around the wearer's thighs and uses struts that extends upwards to a hip joint that is located on the outer area of the wearer's hips. From the hip joints, upper struts extend upwards to a chest mounted plate. In this regard, this device is similar to the Laevo 2.57 device. The hip joints can be released to enable the wearer to walk without restriction. When they are locked in place, trunk flexion loads the mechanism to assist the wearer adopt a forward flexed trunk posture and to provide a low level of assistance when moving their trunk back up to an

upright posture. There are small device adjustment levers around the hips that control the status of the hip joints (open or closed) and the level of assistance provided.

7. **Laevo Flex, by Laevo (active / rigid)**

   The Laevo Flex device is an active and rigid back exoskeleton. It is the most contemporary of the 2 back exoskeletons provided by Laevo. Rather than use elastic or rubber straps to pull downward of the outside of the wearer's spine and potentially increase spinal compression, the Laevo Flex uses 2 rigid steel rods that extend from the rear of the pelvic strap to a plate on back of a vest that worn by the wearer. Rods extend downward from the pelvis to rigid cuffs that extend across the front of the wearer's thighs to provide the lower anchor points. This device is fixed to the wearer's back to ensure that there are no body size or gender biases stemming from the initial chest attachment version of this device (Laevo 2.57 – see below for description). Of the rigid back exoskeletons found within this project, the Laevo Flex device is the only one that anchors the support struts to the wearer's back. The other rigid back devices anchor the struts to the wearer's chest, which can limit their placement and use of females or larger males. This configuration of the upper struts provides a "lifting" effect on the torso when assisting the wearer sustain forward inclined trunk posture rather than a "pulling" effect along their spine – a very different method of delivering posture and extension movement assistance to the wearer. In addition, like other back exoskeletons, the device provides help with the initial rearward movement back to a neutral back posture. Another feature of the Leavo Flex device is that it also has a lateral rotational movement feature at this joint with the wearer's trunk. This enables the wearer to maintain a full range of rotation of their trunk, while retaining trunk assistance, feature only seen with this device. Rods of different length are chosen to fit the different trunk length and body size parameters of the wearer. A number of different sized "power cylinders" are used to choose the desired level of support. Once the desired level is chosen, the activation range is set via adjustments at the smart hip joint. The initial adjustment is made to ensure that the thigh (anchor) cuffs are placed firmly against the wearer's thighs, so subsequent movement creates tension within the device and results in trunk support. Like the other back exoskeletons, the hip joints can be opened to allow the wearer walk without impediment.

8. **Laevo 2.57, by Laevo (passive / rigid)**

   The Laevo F2.57 device is the earlier version of the Laevo Flex device were there the upper section of the support struts insert into a chest bracket at the front of the wearer's torso, rather than their back as used with the Laevo Flex device. This is the 2nd of 3 passive and rigid back exoskeletons. It provides a similar range of adjustment to the Laevo Flex where pressure on the rigid thighs via rigid cuffs is exerted to provide a lower anchor point for forward inclined trunk movements. The upper anchor point is the connection point of the two struts against the wearer's chest. Limitations that may occur as a result of the chest plate have been corrected by the use of the Laevo Flex device that has relocated the upper anchor point to the wearer's back and included a lateral rotational function at this junction to support the wearer's subtle side to side and rotational movements. Like the Laevo Flex, this device provides a torso and back "lifting" action rather than a spinal compression "pulling" action, that is the inherent design feature of the passive and soft back exoskeletons.

9. **Paxeo Back, by Ottobock (passive / rigid)**

   This is the 3rd passive and rigid exoskeleton of the 9 back devices selected. It's mechanism and action are similar to the Back X and Laevo 2.57 devices. Like the other devices, the struts are anchored around the

wearer's thighs and extend up through a hip joint. From here the struts extend up from the hips to a connection point on the wearer's back, between their shoulder blades – similar to the Laevo Flex device. This connection point uses a harness that extends around the wearer's body to their chest to distribute the load over a larger surface area. There are small adjustments of the device activation on a dial at the outside of the hip joints.

Trunk - Neck

10. **Paxeo Neck, by Ottobock (passive / rigid)**

    This device is a passive, rigid neck brace that, when adjusted to fit the wearer's neck size, is able to transfer a proportion of the weight of the wearer's head to the device during head and neck extension. It is a simple device with a specific use to transfer a proportion of the wearer's head weight to the device when they are looking upwards frequently or for a sustained period of time. This device supports a person's head in head/neck extension to reduce the level and duration of activation of their neck muscles when they look upwards frequently and/or for a sustained period of time.

Upper limbs – Shoulders

11. **Hapo Front (was MS), by Ergosante (passive / soft)**

    This exoskeleton uses a streamline harness that extends around the wearer's shoulders but provides a wide pelvic band to provide the anchor point for the lower end of the support struts. From the hips, these struts extend upwards to the triceps cuffs that are anchored around the wearer's upper arm to establish the upper anchor points. Like the Hapo Back device, this lightweight shoulder exoskeleton uses 2 flexible rods to provide the activation assistance. However, rather than being to adjust the level of tension applied to these rods to then adjust the level of activation and assistance, the user has to select one of two rod options before using the device. The different rods provide different levels of assistance, and each would need to be tested by the wearer to establish the level of support that will best suit them. The key features of this design are its simplicity, where there are no mechanical joints, the low profile of the device around the wearer's body and it assistive range, which is approximately 60 to 90 degrees of elevation, a range that is more suited to meat processing work.

12. **Evo Vest, by Ekso Bionics (passive / rigid)**

    The Evo-vest is similar to other passive / rigid shoulder exoskeletons where it has two rear struts that extend upwards from the pelvic belt to support sprung joints beside each shoulder of the wearer. Short struts from these joints extend to provide triceps cuffs that anchor the device to the wearers' upper arms. The rear struts of this device were observed to be more substantive that the other shoulder exoskeletons assessed.

13. **Paxeo Shoulder, by Ottobock (passive / rigid)**

    This shoulder exoskeleton uses 2 separate levers that are anchored to the rear and outer area of the wearer's hips and help in place with a hip belt. These levers extend up to the rear of the wearer's shoulders to a joint that provides a lever with a triceps cuff that enables each unit to be anchored to the wearer's upper arms. The 2 struts are held in place by a central rear back pad. Each strut, between the hip and shoulder has a covered mechanical device that uses adjustable mechanisms and elastic cords to deliver the required

tension to support shoulder elevation. This assistance range of this device is biased towards overhead work where the upper arms will be approximately horizontal.

14. **Exo-01, by Hilti (rebranded Ottobock Paxeo Shoulder) (passive / rigid)**

    This device is the Ottobock Paxeo Shoulder device that has been rebranded as a Hilti exoskeleton. It has the same features as the Paxeo Shoulder device.

15. **Shoulder X, by Suit X/Ottobock (passive / rigid)**

    The Suit X, shoulder X device uses an anchor around the wearer's hips and lower back, and a rear mounted single strut that extends upwards towards the wearer's upper back. Forces applied around the hips are distributed over a larger surface area with the use of a mesh lumber section that is shaped like a lumber support brace. The mesh design should assist the wearer with heat loss. This single pelvic mounted strut extends up along the outer spine to a bracket located between the wearer's shoulder blades. From this bracket, 2 upper arm levers and shoulder joints are attached. The device shoulder joints are rotational in a horizontal plane above the wearer's shoulder joints. From here a short lever extends to the outer side of the wearer's shoulder joints to provide a flexion joint and movement (vertical plane). From this joint a lever extends to the triceps cuff to connect with the wearers upper arm. There are various small control levers at the shoulder joints of the device to enable the shoulder position to be locked or the assistance increased or reduced. This device provides a broad range of shoulder elevation assistance that ranges from 70 to 120 degrees.

Upper limbs – Hands and Fingers

16. **Ironhand, by Bioservo (active / soft)**

    The Ironhand bionic glove is a revolutionary, active and soft device that enhances the wearer's grip capability for the thumb and all fingers. Narrow cables extend along the sides of the fingers and thumb and are gathered in a single covered multicore cable at the base of the wearer's wrist. This cable is extended up and along the wearer's outer forearm and upper arm and held in place within low profile hooks that are located on the surface of circular cuffs that are wrapped around the wearer's forearms and upper arms. A low-profile battery and mechanical lever device are worn within a small backpack or hip-pack, into which the cable connects. Multiple force sensors within the fingers, thumb and palm are activated during gripping and grasping activities. The device responds according to the selected activity profile for the glove where speed of response, level of force exerted, and level of sustained grip can be selected for each finger. In addition, as the wearer performs their required work tasks, an Artificial Intelligence function within the body pack "learns" about the patterns of movements used and adapts the nature of the assistance provided to match these patterns. Essentially this is a smart force assistance device for the hand where, to achieve a unit of hand force exertion, a lesser proportion of this force is delivered and managed by the glove leaving a lower level of force exerted by the wearer to perform the same gripping task. In addition to these innovations and highly relevant features for the meat industry, the Ironhand glove uses the force sensors and grip patterns to provide data can be compared with normative force values to provide ratings of activity and injury risk. That is, this device can also be used as an assessment tool expanding its range of uses and demonstrating a new direction in the design of exoskeletons to use sensors to gather valuable data for analysis and better

understand of the nature of the work being performed. This device is not yet commercially available in Australia and was made available by the developer and manufacturer, Bioservo, for evaluation in the project.

17. **Paxeo Thumb, by Ottobock (passive / rigid)**

    Like the Paxeo Neck device, this device is a fixed dimension, rigid splint worn on the thumb. Once donned, it provides passive support and distribute thumb pressure over a greater surface area and restricts the movement of the distal (end) joint of the thumb when it grasps a tool, object or material. There are 2 versions of this device. One that provides a smooth thumb pad surface and a second that has a small bar that extend across the pad of the thumb. This version with the bar was reported to have been developed for the red meat processing industry in USA where the small bar was reported to enhance leverage and reduce grip effort to grasp and use a knife. There are 6 different sizes of both versions of this device. However, this may not be sufficient to accommodate the very wide range of thumb sizes that will occur within the culturally diverse cross section of the Australian meat processing industry.

Lower limbs – Hips and Knees

18. **Leg X, by Suit X/Ottobock (active / rigid)**

    This third exoskeleton from Suit X completes the whole of body possibility for a wearer. The device is anchored around the hips at the upper end and the user's feet/shoes at ground level. The struts extend along the outer side of the wearer's upper and lower leg and use corresponding hip, knee and ankle joints. This device is powered so it can provide assistance to extend the hip and knee joints when the wearer is moving up from a squatting or flexed lower limb posture. However, it is mostly designed for relatively static work where a person needs to adopt and maintain a squatting/semi-squatting posture frequently or for extended periods. The device can help to hold the body in this position and extended levers at ground level expand the wearer's base of support to reduce their risk of them loosing balance and falling. The powered feature provides additional assistance for the wearer to help them move back up to a neutral standing position from the squatting posture that had been using.

19. **Chairless chair, by Noonee (passive / rigid)**

    This novel device has a similar design and features to the Leg X device. However, its design is oriented towards assisting the wearer to adopt a propping or semi-sitting posture, rather than a squatting posture that would use greater hip and knee flexion. Hence the name the Chairless chair. This device could be suited to supporting a person in this position to perform relative static work tasks in a single location. The Chairless chair can be adjusted to suit the leg length of different users and provides extended struts at ground level to improve the wearer's base of support when in the propped position.

4.2 Stage 2 – Laboratory based testing of selected devices

4.2.1 Device familiarisation – per device

As selected exoskeletons were received, the manufacturer instructions were read and understood. Each device was then assembled, and initial testing and use was conducted to become familiar with the:

1. General features.

2. Fitment features, how the device is adjusted before donning and once it has been put on for optimal fit.
3. How the device felt when walking a moderate distance and being worn for up to one hour.
4. How the device is removed after use (doffed).
5. Mechanism that provides assistance, how it works, and how it is set up and adjusted when it is worn.
6. Methods and equipment that could be used to clean the device after use.
7. Maintenance requirements of the device.
8. Overall suitability for use with the red meat processing industry.
9. General safety features.

As each device became familiar, the type of jobs that it may assist was considered.

4.2.2 Testing & evaluation methods – per device

For some devices, electromyography sensors were used to gauge the impact of the device's activation on reducing muscle use for the same tasks. These tests were exploratory to see if a measurable difference could be seen between the device's assistance mechanism being activated and the assistance being turned off or the device not being worn. These measurements did not represent a formal study of these impacts and were used to provide indicative data to help understand the level of impact that may be possible and what the implications would be for further testing with specific jobs within the meat processing industry.

4.3 Stage 3 – Site (processor) based testing of selected devices

The familiarisation and initial evaluation assessments provided a strong indication of those devices most likely to be usable within the meat processing industry. Discussions with industry stakeholders who had been trialling exoskeletons were also conducted to understand their experiences and any benefits or limitations.

4.3.1 Devices tested

This resulted in eight devices being selected for further operational testing within meat processing facilities. These devices were largely selected on the basis of their higher potential to be incorporated within the day-to-day operations of meat processors in the short term. The key criteria for selection for these devices were their likely usefulness and impact on assisting employees to perform physical task and the ability to clean each device at the end of a working day so it is ready for use on the following day. The selected devices are listed below in priority order.

1. Ironhand glove (Bioservo).
2. Hapo Front – shoulders (Ergosante).
3. Hapo Back (Ergosante).
4. Laevo Flex (Laevo).
5. Apex Back (Herowear).
6. Bionic Back (hTRIUS).
7. Paxeo Back (Ottobock).
8. Paxeo Thumb (Ottobock).

Please note that this selection of these devices should not be interpreted as a rejection of the other devices. Moreover, it reflects a degree of expediency in conducting operational tests within processing plants where the

ability to rigorously trial 19 devices was not considered to be realistic, and the project objectives required consideration of devices that can be implemented sooner than later.

4.3.2 Testing undertaken

Five Australian red meat processors were approached to determine if they had capacity to host the testing of the selected exoskeletons. Four of these processors were in Victoria, which was the most accessible state for this testing, and one was located in Queensland. In the end two processors were able to host this testing, a beef processing facility in Victoria and a beef plant in Queensland. However, time constraints and the utilisation of only two participating processors, limited the range of devices that could be and were tested.

Of all the exoskeletons procured, the standout device was the Ironhand bionic glove by the Swedish company, Bioservo. This device provides grip assistance for the wearer, so they do not have to exert as much muscular effort to grasp a knife, tools and parts of the carcase during production (slaughter) and processing (boning and slicing).

Given the inherent requirement for many meat processing jobs to establish and maintain grasp of a tool and part of a carcase, the potential impact of the Ironhand glove was considered to not only be substantial, but potentially revolutionary. In addition, the advanced design approach for this exoskeleton has anticipated the industrial requirement of having to clean the device on a daily basis after use. The Ironhand glove and harness are placed in a laundry bag provided by Bioservo so it can be machine washed along with an employee's personal protective clothing. The disassembly of the device only takes seconds to separate the glove and its "pulling" mechanism and the powerpack, making it very easy to prepare for washing and re-assembly after it has been cleaned. The backpack or pelvic pack in which the power unit and computing/coordinating function is contained during use is also easily separated from the power pack for cleaning and is placed in the laundry bag with the glove for washing.

Operational testing within the two participating processors focused on trialling and evaluating the Ironhand glove. The other devices were taken to each site and demonstrated the hosts. However, both participating plants supported the focus on testing and better understanding the function of the glove as they recognised its potential for high impact within the industry.

This testing involved the following activities:

1. Fitting the glove onto the participant's dominant (knife) hand.
2. Setting up the participant as a user of the glove.
3. Calibrating the glove to establish maximum force exertion values. All subsequent data is expressed as a proportion of these maximum force values.
4. Instructing the participant how to activate the emergency stop switch that is mounted at the front of one of the shoulder/chest straps of the body pack or the front belt of the pelvic pack.
5. Assisting the participant to become familiar with wearing and using the device.
6. Determining the level of glove protection needed, where only a maximum of 3 gloves, including the device, could be worn without compromising hand function.
7. Setting the assistive power of the device at an initial level of 50%.
8. Allowing the participant to perform their usual work while wearing the glove.
9. Increasing the assistance level one level (12.5 %) at a time after the participant became familiar with using the glove and they felt comfortable confident in trialling and higher setting. This process occurred until the participant felt that any additional power would be excessive. For two participants, the upper level was reduced after they considered it to be too high.

10. Testing different levels of individual finger assistance to identify if this was noticeable to the participant.
11. Trialling the non-dominant hand for two of the three participants so they could test the glove while gripping parts of the carcase while using a knife, or other tool, to bone, slice and trim the carcase.
12. Obtaining feedback from each participant during and after each trial period.

4.3.3 Review of results & preparation of the project report

The assessments of each device, processor feedback and the onsite testing of the Ironhand glove were consolidated and reviewed for inclusion in this report

In addition to describing recommendations for device implementation, three additional outcomes were delivered within the project report:

1. Establishment of an industry reference group to guide and facilitate the greater engagement between emerging human assistance technologies and the Australian Red Meat Processing industry.
2. A road map to define how this reference group may operate to assist the Australian red meat processing industry to obtain optimum advantage from these technologies.
3. Guidelines to assist meat processors evaluate and implement exoskeletons, using a 5-step process.

5.0 Project Outcomes

This primary outcome of this project was the identification of devices that are suited for short to medium term use within meat processing facilities in Australia to improve the balance between physical work demands and the capacity of people to perform these demands. It is not possible to predict likely long-term use of any device within this industry as there are too many unknown factors. The devices most suited to short to medium term use include the powered glove, several trunk and shoulder devices, and thumb splints *(see details in Sections 5.3 and 5.4 below)*. The devices not recommended for implementation were found to be effective and functional as exoskeletons and the main reasons for their exclusion at this time is the complexity of cleaning them after daily use.

The project delivered an additional range of diverse outcomes that went beyond the selection of exoskeletons for implementation. These additional outcomes include the identification of a broader range of strategies that might steer the industry to get best use of assistive devices for jobs that require this assistance as well as increasing the use of data gathering within exoskeletons so they can establish a pathway to better inform how increased mechanisation and eventual automation, or semi-automation of industry jobs may occur.

The following outcomes were achieved within this project:

1. Literature review.
2. A simple categorization method for exoskeletons to understand their core attributes relative to the meat processing environment.
3. Selection and procurement of 19 exoskeletons for evaluation.
4. Exoskeleton evaluation outcomes.
5. Development of a step-by-step process to guide meat processors in the evaluation and implementation of exoskeletons and other human assistance technologies such as cobotic devices and collaborative robots.

6. Development of a state of knowledge regarding the rapidly emerging exoskeleton industry, innovative devices being developed and the opportunities that exist for the Australian red meat processing industry.
7. Identification of the benefits of defining the nature of meat processing jobs and tasks to drive the development of exoskeletons and other human assistance technologies.

5.1 Literature review

Of the recent limited scientific literature available on exoskeletons, the studies undertaken and cited have focused on quantifying the mechanical impact of the worn device and testing functionality within “clean” occupational settings, such as automotive assembly. The broader issues of fit and comfort, bulkiness of the device, if there are any catching or snagging points, are described and in some cases studied.

A key limitation with the current research into exoskeleton design and use is that recently designed and emerging devices are not yet included in this research, and there is a limited ability to extrapolate findings into the range of complex environments of the meat processing industry.

In summary, while general information on the range of approaches taken to conduct the range of studies found, the literature review did not reveal any results or initiatives that could be substantially incorporated into this project.

A key finding of this project was the difficulty in extrapolating the results of laboratory studies into real world industrial situations. In research terms, this is known as external validity and reflects the ability to generalise the findings of a study to broader circumstances. Studies with limited subject group sizes and expertise in highly controlled settings are essential to evaluate the mechanical impact on the wearer of an exoskeleton when using the device by measuring muscle activity of the targeted muscle groups for the same limited task. In other words, does the device do what the developer intends or claims to do.

In laboratory studies, variance in how tasks are performed can be limited and controlled to limit overall variance in the results so any variance can be attributed to the effect of wearing, or not wearing, the device. In this type of study design, the level of exoskeleton assistance provided to the wearer can be varied from none at all to maximal tolerable and safe levels. While the results of this type of study can deliver compelling evidence to support further testing and evaluation of the device within workplace settings, these results themselves are not sufficient predictors of the likelihood of success of that device.

Longer term studies of the utilisation of devices in workplace settings are required to develop the required level of understanding of the actual impact of wearing exoskeletons to help people perform physical tasks.

A difficulty in undertaking these types of studies are the rapid advances in exoskeleton technologies. Developers of worn human assistance devices operate within a rapidly emerging and highly competitive global market. Existing devices are being continually improved and upgraded while new, often very creative assistive devices are being continually introduced early to the market. At times, some of these devices may be introduced too early and may not sufficiently accommodate the broad range of fit needed across a large population of workplace-based users, or the levels of adaptation and device functionality to suit the particular requirements of an industrial environment and specialised jobs, as is found across the Australian red meat processing industry.

Accordingly, there were no significant revelatory insights obtained from this literature review. The list of references review is described in Section 8 of this report.

5.2 Simple exoskeleton categorization method for meat processing

As more information was gathered about the different characteristics of available devices, options of categorising them became apparent. Two clear features to categorise exoskeletal devices became obvious:

1. **Active or passive:**
    a. Active devices use an external source of power to generate and control the assistive movement(s) of the exoskeleton. The most common power source is electrical where the device will use a rechargeable battery. Using active devices requires spare batteries to be ready for change over during an 8-hour shift, depending on their level of use. For some devices, such as the Bioservo Ironhand bionic glove, a battery with an 8-hour capacity has been chosen to ensure continuity of use and reduce the inconvenience of needing to replace it if it fully discharges at an unpredictable time.
    Of the 19 devices obtained for this project, 4 devices were active. Only 1 of these devices was included in site-based testing, the Bioservo Ironhand device.
    At least 4 other active exoskeletons were identified during the initial search, however the developers/manufacturers either did not respond to multiple enquiries or declined to provide and support a device for evaluation into Australia. The significance of this is that the consideration of active devices within this project was inherently under-represented and more of these devices should be included in any future investigations.
    b. Passive exoskeletons use mechanical devices such as springs, levers or elastic cords or rubber straps to resist movements as it approaches the end of an adjusted range or to hold one or more joints within a range of movement.
    c. of movements increases. These devices are adjusted so they provide greatest resistance at a desired angle of movement.
2. **Soft or rigid:**
    a. Soft exoskeletons use soft and flexible structures and don't have any rigid components
    b. Rigid exoskeletons use a combination of rigid structures to support the body part being assisted with soft straps and padding to enable the user to don and adjust the device for comfort.

As a combination of well-established and innovative emerging devices were discovered, the manufacturer was approached to see if they would provide a device into Australia for evaluation within the project. From those organisations that responded, most were prepared for AMPC to procure a device, even when they have no distributors within Australia that could provide support. For devices found to be highly innovative, repeated attempts to procure one or more devices were made until they relented. While several devices, in particular powered back and shoulder devices, were assessed as being relevant to the meat processing industry, it was not possible to procure them for testing at that time.

5.3 Selection & procurement of 19 exoskeletons for testing

5.3.1 Exoskeletons procured for evaluation & their key features

A summary of the key features and functions of each device is described below. The evaluation of these devices considered the key design and functional features of:

1. Fitting a wide range of possible users.
2. Nature of the assistance actions, how they work and are adjusted.
3. The profile of the worn device around a person's and how heat loss is managed.
4. How the devices can be protected within the meat processing environment.
5. How the devices can be cleaned after use on a daily basis to match industry standards.

5.3.1.1 Trunk - Back

1. **Hal-LB01, by Cyberdyne (active / rigid)**

   This is an active rigid device that is fitted around the wearer's pelvis. Its activation provides assistance for forward and rearward low back movements. It is primarily used to assist patients with neurological condition to support their trunk movement.

2. **Japet (corset), by Japet (active / rigid)**

   This active device is a rigid corset that fits firmly over the outer boney crests of the wearer's pelvis and underneath their ribcage on each side of their body. There are 4 actuators that push the anchored sections of the corset upwards, 2 on each side at the front and 2 at the rear. There are 5 activation level settings that create the upward pushing movement for each of the actuators. Their activation creates a traction effect on the wearer's lower spine while the person is upright. It also limits their capacity to flex their lumbar spine for forward and lower reaching tasks, where the wearer needs to use greater hip and knee flexion to replace this limited low back movement.

3. **Apex, by Herowear (passive / soft)**

   This is a passive and soft exoskeleton device. It is secured to the wearer's torso via a soft harness that extends around the wearer's shoulders and pelvic. There are a range of different sizes or lengths of flat rubber straps. These provide the required energy and are activated when the wearer moves into a flexed trunk position. Different sized straps must be selected and fitted to match the body height and back length of the wearer. These straps are anchored from the wearer's lower back to straps around their thighs. As the person leans or bend forward, the straps are elongated and put under tension or "energised." Apart from selecting the correct strap size as the main form of activation adjustment, this device has an adjustment feature where the wearer can activate a switch that is mounted on the left chest strap to lock and hold the tension of the strap in that selected position. With the position locked in place, the device can help the wearer to maintain that inclined posture, because of the tension that is applied to the strap, or the energy absorption in the strap increases when the wearer moves further forward, providing them with a "kick" when they initiate the extension movement to reassume an upright posture. The locking device can be easily disengaged to release the tension on the strap and allow it to be reset for the next position. The wearer is able to walk when there is no tension applied to the rubber thigh straps.

4. **Bionic Back, by hTRIUS (passive / soft)**

   This is another passive and soft exoskeleton to assist back inclination and extension movements. It uses a soft backpack style harness that extend around the wearer's shoulders and pelvic. The support straps are anchored around the wearer's thighs, like the Herowear Apex device. The level of tension and assistance provided is adjusted by pulling on 2 tabs located at the wearer's hips. The further these tabs are pulled forward, the greater the "loaded" tension that is applied to the device. These levels of resistance to trunk

forward inclination provide support for the adoption of a flexed trunk posture, according to the chosen setting. This tension can be quickly released by “flicking” a small plastic clamp on each strap to the open position, providing readily accessible and usable methods of increasing and reducing this tension and level of device activation. Releasing this tension is done to enable the wearer to walk without restricting their movement.

5. **Hapo Back, by Ergosante (passive / soft)**

   This is third and final passive and soft back exoskeleton. The core design uses a soft harness that is secured around the wearer’s shoulders, pelvis and thighs. This innovative device uses flexible fibreglass rods on each side of the wearers body, that extend up from the anchor straps around the thigh, through a restraining loop at the hips, up to the lower section of the chest/shoulder strap. When the wearer moves to a forward inclined trunk posture, tension is applied to the rod to assist them to maintain a static flexed posture and to provide a movement “kick” when the wearer starts to move back to the upright position. The level of tension on the rod, and therefore the level of assistance provided, is adjusted by pulling on the loop strap at the wearer’s hips. Pulling this strap moves the rod further forward increasing tension within it when the wearer’s torso bends forward. To enable the wearer to walk, brackets within the rods at hip level are released and “break” the rod. With this broken, the rods above and below this point move freely without applying any tension at the shoulder and thigh anchor points. The wearer is then free to walk and move about with no restrictions. Once the wearer is ready to activate the device again, they simply adopt an upright posture and lower the brackets down and along the rod to reform its solid continuous length. During the project two different versions were provided. The older version initially provided used inflatable chest/shoulder supports as a method of distributing load over a broad surface area. The updated version replaced these with soft chest/shoulder pads that were consistent with those used on other soft back exoskeleton devices.

6. **Back X, by Suit X/Ottobock (passive / rigid)**

   The Back X device is a passive and rigid back exoskeleton. The device anchors around the wearer’s thighs and uses struts that extends upwards to a hip joint that is located on the outer area of the wearer’s hips. From the hip joints, upper struts extend upwards to a chest mounted plate. In this regard, this device is similar to the Laevo 2.57 device. The hip joints can be released to enable the wearer to walk without restriction. When they are locked in place, trunk flexion loads the mechanism to assist the wearer adopt a forward flexed trunk posture and to provide a low level of assistance when moving their trunk back up to an upright posture. There are small device adjustment levers around the hips that control the status of the hip joints (open or closed) and the level of assistance provided.

7. **Laevo Flex, by Laevo (active / rigid)**

   The Laevo Flex device is an active and rigid back exoskeleton. It is the most contemporary of the 2 back exoskeletons provided by Laevo. Rather than use elastic or rubber straps to pull downward of the outside of the wearer’s spine and potentially increase spinal compression, the Laevo Flex uses 2 rigid steel rods that extend from the rear of the pelvic strap to a plate on back of a vest that worn by the wearer. Rods extend downward from the pelvis to rigid cuffs that extend across the front of the wearer’s thighs to provide the lower anchor points. This device is fixed to the wearer’s back to ensure that there are no body size or gender biases stemming from the initial chest attachment version of this device (Laevo 2.57 – see below for

description). Of the rigid back exoskeletons found within this project, the Laevo Flex device is the only one that anchors the support struts to the wearer's back. The other rigid back devices anchor the struts to the wearer's chest, which can limit their placement and use of females or larger males. This configuration of the upper struts provides a "lifting" effect on the torso when assisting the wearer sustain forward inclined trunk posture rather than a "pulling" effect along their spine – a very different method of delivering posture and extension movement assistance to the wearer. In addition, like other back exoskeletons, the device provides help with the initial rearward movement back to a neutral back posture. Another feature of the Leavo Flex device is that it also has a lateral rotational movement feature at this joint with the wearer's trunk. This enables the wearer to maintain a full range of rotation of their trunk, while retaining trunk assistance, feature only seen with this device. Rods of different length are chosen to fit the different trunk length and body size parameters of the wearer. A number of different sized "power cylinders" are used to choose the desired level of support. Once the desired level is chosen, the activation range is set via adjustments at the smart hip joint. The initial adjustment is made to ensure that the thigh (anchor) cuffs are placed firmly against the wearer's thighs, so subsequent movement creates tension within the device and results in trunk support. Like the other back exoskeletons, the hip joints can be opened to allow the wearer walk without impediment.

8. **Laevo 2.57, by Laevo (passive / rigid)**

   The Laevo F2.57 device is the earlier version of the Laevo Flex device were there the upper section of the support struts insert into a chest bracket at the front of the wearer's torso, rather than their back as used with the Laevo Flex device. This is the 2nd of 3 passive and rigid back exoskeletons. It provides a similar range of adjustment to the Laevo Flex where pressure on the rigid thighs via rigid cuffs is exerted to provide a lower anchor point for forward inclined trunk movements. The upper anchor point is the connection point of the two struts against the wearer's chest. Limitations that may occur as a result of the chest plate have been corrected by the use of the Laevo Flex device that has relocated the upper anchor point to the wearer's back and included a lateral rotational function at this junction to support the wearer's subtle side to side and rotational movements. Like the Laevo Flex, this device provides a torso and back "lifting" action rather than a spinal compression "pulling" action, that is the inherent design feature of the passive and soft back exoskeletons.

9. **Paxeo Back, by Ottobock (passive / rigid)**

   This is the 3rd passive and rigid exoskeleton of the 9 back devices selected. It's mechanism and action are similar to the Back X and Laevo 2.57 devices. Like the other devices, the struts are anchored around the wearer's thighs and extend up through a hip joint. From here the struts extend up from the hips to a connection point on the wearer's back, between their shoulder blades – similar to the Laevo Flex device. This connection point uses a harness that extends around the wearer's body to their chest to distribute the load over a larger surface area. There are small adjustments of the device activation on a dial at the outside of the hip joints.

5.3.1.2 Trunk - Neck

10. **Paxeo Neck, by Ottobock (passive / rigid)**

    This device is a passive, rigid neck brace that, when adjusted to fit the wearer's neck size, is able to transfer a proportion of the weight of the wearer's head to the device during head and neck extension. It is a simple

device with a specific use to transfer a proportion of the wearer's head weight to the device when they are looking upwards frequently or for a sustained period of time. This device supports a person's head in head/neck extension to reduce the level and duration of activation of their neck muscles when they look upwards frequently and/or for a sustained period of time.

5.3.1.3 Upper limbs – Shoulders

11. **Hapo Front (was MS), by Ergosante (passive / soft)**

    This exoskeleton uses a streamline harness that extends around the wearer's shoulders but provides a wide pelvic band to provide the anchor point for the lower end of the support struts. From the hips, these struts extend upwards to the triceps cuffs that are anchored around the wearer's upper arm to establish the upper anchor points. Like the Hapo Back device, this lightweight shoulder exoskeleton uses 2 flexible rods to provide the activation assistance. However, rather than being to adjust the level of tension applied to these rods to then adjust the level of activation and assistance, the user has to select one of two rod options before using the device. The different rods provide different levels of assistance, and each would need to be tested by the wearer to establish the level of support that will best suit them. The key features of this design are its simplicity, where there are no mechanical joints, the low profile of the device around the wearer's body and it assistive range, which is approximately 60 to 90 degrees of elevation, a range that is more suited to meat processing work.

12. **Evo Vest, by Ekso Bionics (passive / rigid)**

    The Evo-vest is similar to other passive / rigid shoulder exoskeletons where it has two rear struts that extend upwards from the pelvic belt to support sprung joints beside each shoulder of the wearer. Short struts from these joints extend to provide triceps cuffs that anchor the device to the wearers' upper arms. The rear struts of this device were observed to be more substantive that the other shoulder exoskeletons assessed.

13. **Paxeo Shoulder, by Ottobock (passive / rigid)**

    This shoulder exoskeleton uses 2 separate levers that are anchored to the rear and outer area of the wearer's hips and help in place with a hip belt. These levers extend up to the rear of the wearer's shoulders to a joint that provides a lever with a triceps cuff that enables each unit to be anchored to the wearer's upper arms. The 2 struts are held in place by a central rear back pad. Each strut, between the hip and shoulder has a covered mechanical device that uses adjustable mechanisms and elastic cords to deliver the required tension to support shoulder elevation. This assistance range of this device is biased towards overhead work where the upper arms will be approximately horizontal.

14. **Exo-01, by Hilti (rebranded Ottobock Paxeo Shoulder) (passive / rigid)**

    This device is the Ottobock Paxeo Shoulder device that has been rebranded as a Hilti exoskeleton. It has the same features as the Paxeo Shoulder device.

15. **Shoulder X, by Suit X/Ottobock (passive / rigid)**

    The Suit X, shoulder X device uses an anchor around the wearer's hips and lower back, and a rear mounted single strut that extends upwards towards the wearer's upper back. Forces applied around the hips are distributed over a larger surface area with the use of a mesh lumber section that is shaped like a lumber support brace. The mesh design should assist the wearer with heat loss. This single pelvic mounted strut extends up along the outer spine to a bracket located between the wearer's shoulder blades. From this

bracket, 2 upper arm levers and shoulder joints are attached. The device shoulder joints are rotational in a horizontal plane above the wearer's shoulder joints. From here a short lever extends to the outer side of the wearer's shoulder joints to provide a flexion joint and movement (vertical plane). From this joint a lever extends to the triceps cuff to connect with the wearers upper arm. There are various small control levers at the shoulder joints of the device to enable the shoulder position to be locked or the assistance increased or reduced. This device provides a broad range of shoulder elevation assistance that ranges from 70 to 120 degrees.

5.3.1.4 Upper limbs – Hands and Fingers

16. **Ironhand, by Bioservo (active / soft)**

    The Ironhand bionic glove is a revolutionary, active and soft device that enhances the wearer's grip capability for the thumb and all fingers. Narrow cables extend along the sides of the fingers and thumb and are gathered in a single covered multicore cable at the base of the wearer's wrist. This cable is extended up and along the wearer's outer forearm and upper arm and held in place within low profile hooks that are located on the surface of circular cuffs that are wrapped around the wearer's forearms and upper arms. A low-profile battery and mechanical lever device are worn within a small backpack or hip-pack, into which the cable connects. Multiple force sensors within the fingers, thumb and palm are activated during gripping and grasping activities. The device responds according to the selected activity profile for the glove where speed of response, level of force exerted, and level of sustained grip can be selected for each finger. In addition, as the wearer performs their required work tasks, an Artificial Intelligence function within the body pack "learns" about the patterns of movements used and adapts the nature of the assistance provided to match these patterns. Essentially this is a smart force assistance device for the hand where, to achieve a unit of hand force exertion, a lesser proportion of this force is delivered and managed by the glove leaving a lower level of force exerted by the wearer to perform the same gripping task. In addition to these innovations and highly relevant features for the meat industry, the Ironhand glove uses the force sensors and grip patterns to provide data can be compared with normative force values to provide ratings of activity and injury risk. That is, this device can also be used as an assessment tool expanding its range of uses and demonstrating a new direction in the design of exoskeletons to use sensors to gather valuable data for analysis and better understand of the nature of the work being performed. This device is not yet commercially available in Australia and was made available by the developer and manufacturer, Bioservo, for evaluation in the project.

17. **Paxeo Thumb, by Ottobock (passive / rigid)**

    Like the Paxeo Neck device, this device is a fixed dimension, rigid splint worn on the thumb. Once donned, it provides passive support and distribute thumb pressure over a greater surface area and restricts the movement of the distal (end) joint of the thumb when it grasps a tool, object or material. There are 2 versions of this device. One that provides a smooth thumb pad surface and a second that has a small bar that extend across the pad of the thumb. This version with the bar was reported to have been developed for the red meat processing industry in USA where the small bar was reported to enhance leverage and reduce grip effort to grasp and use a knife. There are 6 different sizes of both versions of this device. However, this may not be sufficient to accommodate the very wide range of thumb sizes that will occur within the culturally diverse cross section of the Australian meat processing industry.

5.3.1.5 Lower limbs – Hips and Knees

18. **Leg X, by Suit X/Ottobock (active / rigid)**

    This third exoskeleton from Suit X completes the whole of body possibility for a wearer. The device is anchored around the hips at the upper end and the user's feet/shoes at ground level. The struts extend along the outer side of the wearer's upper and lower leg and use corresponding hip, knee and ankle joints. This device is powered so it can provide assistance to extend the hip and knee joints when the wearer is moving up from a squatting or flexed lower limb posture. However, it is mostly designed for relatively static work where a person needs to adopt and maintain a squatting/semi-squatting posture frequently or for extended periods. The device can help to hold the body in this position and extended levers at ground level expand the wearer's base of support to reduce their risk of them loosing balance and falling. The powered feature provides additional assistance for the wearer to help them move back up to a neutral standing position from the squatting posture that had been using.

19. **Chairless chair, by Noonee (passive / rigid)**

    This novel device has a similar design and features to the Leg X device. However, its design is oriented towards assisting the wearer to adopt a propping or semi-sitting posture, rather than a squatting posture that would use greater hip and knee flexion. Hence the name the Chairless chair. This device could be suited to supporting a person in this position to perform relative static work tasks in a single location. The Chairless chair can be adjusted to suit the leg length of different users and provides extended struts at ground level to improve the wearer's base of support when in the propped position.

5.3.2 Exoskeletons considered but not yet available in Australia

Other manufacturers and the devices of interest were identified, but it was not possible to engage with them procure these devices. These include:

1. German Bionic – CrayX (active back exoskeleton).
2. Panasonic – Atoun model Y (active back exoskeleton).
3. Comau – Mate-XT (passive shoulder exoskeleton).

It is proposed that the review of available and emerging device be updated and, if relevant, these groups, as well as any new developers and manufactures, should be approached to determine the current design features of the devices and determine if they should be procured for evaluation.

5.4 Exoskeleton evaluation outcomes

After the evaluation process conducted within the project, the exoskeletons were placed into one of two groups:

1. Exoskeletons chosen for evaluation.
2. Exoskeletons to be further considered or excluded at this time.

5.4.1 Exoskeletons chosen for evaluation

The following devices were selected for inclusion in the Stage 3 site-based evaluations. A brief reason for the inclusion of each device is also provided. The inclusion of each device for further testing should be seen as a judgement of its ability to be a likely fit within this environment and the device having been assessed and likely to

provide and advantage to users even if protection if required. In addition, these devices are more likely to be able to be cleaned on a daily basis using conventional cleaning and laundry methods within the meat processing industry.

Trunk - Back

1. #3 Apex 1 & 2, by Herowear (passive / soft)
2. #4 Bionic Back, by hTRIUS (passive / soft)
3. #5 Hapo Back, by Ergosante (passive / soft)
4. #7 Laevo Flex, by Laevo (passive / rigid)

Upper limbs – Shoulders

1. #11 Hapo Front (was MS), by Ergosante (passive / rigid)

Upper limbs – Hands and Fingers

1. #17 Ironhand, by Bioservo (active / rigid)
2. #18 Paxeo Thumb, by Ottobock (passive / rigid)

5.4.1.1 Trunk - Back

#3 Apex 1 & 2, by Herowear (passive / soft)

- This device is easily adjusted for fit and function.
- This device has a novel adjustment feature that enables different tension to be set at different postures.
- The back setting can be easily adjusted for walking mode.
- The device can be protected by wearing a smock or over jacket.
- The whole unit can be folded up, placed in a bag and washed in a conventional meat processing laundry with other employee PPC items.

#4 Bionic Back, by hTRIUS (passive / soft)

- This device is easily adjusted for fit and function.
- The back setting can be easily adjusted for walking mode.
- The device can be protected by wearing a smock or over jacket.
- The whole unit can be folded up, placed in a bag and washed in a conventional meat processing laundry with other employee PPC items.

#5 Hapo Back, by Ergosante (passive / soft)

- This device is easily adjusted for fit and function.
- This device has a novel feature that applies force to the back via side struts to help elevate or hold it in place, rather than using elastic or rubber to pull down along the outside of the back like the Herowear Apex 1 and 2 and hTRIUS Bionic Back devices.
- The back setting can be easily adjusted for walking mode.
- The device can be protected by wearing a smock or over jacket.
    - The whole unit can be dissembled and the soft components placed in a bag and washed in a conventional meat processing laundry with other employee PPC items. The rigid components can be wiped with sanitiser.

#7 Laevo Flex, by Laevo (passive / rigid)

- This device is easily adjusted for fit and function.

- This device has a novel feature that applies force to the back via side struts to help elevate or hold it in place, rather than using elastic or rubber to pull down along the outside of the back like the Herowear Apex 1 and 2 and hTRIUS Bionic Back devices.
- This force is applied via the wearer's back, not their front/chest avoiding possible compression of the wearer's breast tissue.
- The back setting can be easily adjusted for walking mode.
- The device can be protected by wearing a smock or over jacket.
- The soft components can be removed for washing in a conventional meat processing laundry while the rigid components can be wiped down with sanitiser to clean this device.

5.4.1.2 Upper limbs – Shoulders

#11 Hapo Front (was MS), by Ergosante (passive / rigid)

- This device is easily adjusted for fit and function.
- The device can be protected by wearing a smock or over jacket.
- The whole unit can be dissembled and the soft components placed in a bag and washed in a conventional meat processing laundry with other employee PPC items. The rigid components can be wiped with sanitiser.

5.4.1.3 Upper limbs – Hands and Fingers

#17 Ironhand, by Bioservo (active / rigid)

- This soft but active device provides highly compelling features for the meat processing industry for
- numerous tasks that require forceful and repeated grasping of a knife and soft wet product, be it skin, fat, offal or a cut of meat.
- The device can be easily protected and cleaned using conventional laundry methods.

#18 Paxeo Thumb, by Ottobock (passive / rigid)

- This is a simple thumb splint that can be worn under and outer glove.
- It can be cleaned by wiping it down or being washed.

5.4.2 Exoskeletons to be further considered or excluded at this time

The following devices were excluded from the Stage 3 site-based evaluations. A brief reason for the exclusion of each device is also provided. The exclusion of each device from further testing should not be seen as a judgement against the device and its fit and functionality. Moreover, exclusion was based on the level of protection that would be needed within the meat processing environment, the complexity of cleaning it and the complexity of adjusting the assistive features within this environment.

Trunk - Back

1. #1 Hal-LB01, by Cyberdyne (active / rigid)
2. #2 Japet (corset), by Japet (active / rigid)
3. #6 Back X, by Suit X/Ottobock (passive / rigid)
4. #8 Laevo 2.57, by Laevo (passive / rigid)
5. #9 Paxeo Back, by Ottobock (passive / rigid)

Trunk - Neck

1. #10 Paxeo Neck, by Ottobock (passive / rigid)

Upper limbs – Shoulders

1. #12 Evo Vest, by Ekso Bionics (passive / rigid)
2. #13 Paxeo Shoulder, by Ottobock (passive / rigid)
3. #14 Exo-01, by Hilti (rebranded Ottobock Paxeo Shoulder) (passive / rigid)
4. #15 Shoulder X, by Suit X/Ottobock (passive / rigid)

Lower limbs – Hips and Knees

1. #19 Leg X, by Suit X/Ottobock (active / rigid)
2. #20 Chairless chair, by Noonee (passive / rigid)

5.4.2.1 Trunk - Back

#1 Hal-LB01, by Cyberdyne (active / rigid)

- Device not received and stage 2 evaluation not conducted.

#2 Japet (corset), by Japet (active / rigid)

- Device is complex to fit and likely to only fit users with slender torsos.
- Precise fitment of the device needed and fit likely to be uncomfortable for most potential users.

#6 Back X, by Suit X/Ottobock (passive / rigid)

- Daily cleaning of the device assessed as being difficult.
- Adjustment of the assistive features assessed as being complex within the meat processing environment.

#8 Laevo 2.57, by Laevo (passive / rigid)

- This device is easily adjusted for fit and function.
- This device has a novel feature that applies force to the back via side struts to help elevate or hold it in place, rather than using elastic or rubber to pull down along the outside of the back like the Herowear Apex 1 and 2 and hTRIUS Bionic Back devices.
- This force is applied via the wearer's front/chest which may be awkward or uncomfortable on the breast tissue of some wearers
- The back setting can be easily adjusted for walking mode.
- The device can be protected by wearing a smock or over jacket.
- The soft components can be removed for washing in a conventional meat processing laundry while the rigid components can be wiped down with sanitiser to clean this device.

#9 Paxeo Back, by Ottobock (passive / rigid)

- Daily cleaning of the device assessed as being difficult.
- Adjustment of the assistive features assessed as being complex within the meat processing environment.

5.4.2.2 Trunk - Neck

#10 Paxeo Neck, by Ottobock (passive / rigid)

- Relevant jobs, requiring sustained looking overhead/neck extension not yet identified.

5.4.2.3 Upper limbs – Shoulders

#12 Evo Vest, by Ekso Bionics (passive / rigid)

- Daily cleaning of the device assessed as being difficult.
- Adjustment of the assistive features assessed as being complex within the meat processing environment.

#13 Paxeo Shoulder, by Ottobock (passive / rigid)

- Daily cleaning of the device assessed as being difficult.
- Adjustment of the assistive features assessed as being complex within the meat processing environment.

#14 Exo-01, by Hilti (rebranded Ottobock Paxeo Shoulder) (passive / rigid)

- Daily cleaning of the device assessed as being difficult.
- Adjustment of the assistive features assessed as being complex within the meat processing environment.

#15 Shoulder X, by Suit X/Ottobock (passive / rigid)

- Daily cleaning of the device assessed as being difficult.
- Adjustment of the assistive features assessed as being complex within the meat processing environment.

5.4.2.4 Lower limbs – Hips and Knees

#19 Leg X, by Suit X/Ottobock (active / rigid)

- Relevant jobs, requiring sustained squatting in a single location not yet identified.

#20 Chairless chair, by Noonee (passive / rigid)

- Relevant jobs, requiring sustained squatting in a single location not yet identified.

5.5 5-step guideline - evaluation & implementation of exoskeletons

During the project, a series of selection and evaluation criteria were progressively developed to guide the selection, procurement, testing and implementation of exoskeletons within the red meat processing industry. These criteria were developed as knowledge and experience of manufacturers, suppliers and the range of devices discovered was gained during the procurement and testing stages. These selection criteria were developed into a guideline reference that uses 5 sequential steps to evaluate the manufacturer/distributor capability, industry needs and selected devices. The final step outlines guidelines for the implementation of any exoskeletons assessed as being suitable.

Also, this guide seeks to assist meat processors to clearly define industry needs in the design and use of exoskeletons to manufacturers/distributors and to identify early in any evaluation process those variables that may exclude or limit the use of a device within this environment, regardless of its level of appeal or sophistication. This guideline reference is presented in summary and detail in Appendix 9.1 of this report and should be used by processors to help fast track their uptake of devices most likely to be suitable and effective within the meat processing industry.

This 5-step process involves the following sequence of considerations:

Step 1 – Manufacturer/distributor evaluation

Evaluation of the capability of the manufacturer and/or distributor to deliver devices and assistance to support the assessment and possible implementation of their devices.

Step 2 – Meat processing industry criteria

Assessment of prospective exoskeleton devices against meat industry criteria to ensure that any device being considered can be safely used, cleaned and maintained in the varied and, at times, extreme environmental and risk mitigation conditions of this industry.

Step 3 – Exoskeleton initial assessment

The initial assessment of prospective devices to identify key features of fit, function and safety to then determine if procurement of devices for testing within the operational environment is likely to be worthwhile. Also, this level of assessment should support the early identification of any risks to food safety or the day-to-day commercial operation of the meat processor that may result from the uptake of these worn devices.

Step 4 – Exoskeleton fit, usability and operational testing

The procurement and operational testing of devices that have passed the criteria of the first three steps of this process. This testing should be conducted for the jobs where the type of assistance provided by a device is likely to be of benefit for employees and where other design improvements to reduce physical work demands are difficult, or not currently practicable, to achieve. All aspects of anticipated use, cleaning and maintenance of devices should be evaluated within this stage to determine if the device will be suitable to implement.

Step 5 – Exoskeleton implementation and consolidation

Devices that satisfy the assessment criteria of the first four steps of this evaluation process are likely to be suitable for implementation. The guidelines within Step 5 provide a comprehensive description of the approach and resources that should be used to optimise the likelihood of successful implementation. Activities within this step include ongoing review of uptake and effectiveness of the device to support its consolidation as a standard item of equipment used within a processor's facility.

The diagram below outlines each step of this evaluation process and how exclusion or progression of a manufacturer/distributor and/or device may proceed after their assessment at each of the first four stages of the process The 5th and final step provides guidelines for the implementation of a chosen device based on the processor's progressive experience in assessing and trialling the device.

5.6 Development of state of knowledge about exoskeletons globally

5.6.1 Emerging trends in exoskeletons

5.6.1.1 Increasing use of design features more compatible with meat processing industry needs

A key current platform in the design of most exoskeletons is the use of structural levers that extend between the joints being support, that are powered by batteries, or springs, to exert the forces required to provide postural, movement and force assistance to the wearer. Typically, these devices are for the low back, shoulder and leg (hip and knee). Many devices developed by the more established manufacturers involve advanced concepts and, increasingly, 2nd and 3rd generations of design that incorporate learning and improvements. However, their use within the red meat processing environment, in the foreseeable future is likely to be restricted due to the:

1. Humid, wet and cold nature of production and processing areas.
2. Risks of small components becoming free and falling into/onto food being produced, threatening food quality and creating commercial risk.

3. Need to establish purpose designed protective coverings for some devices.
4. Requirement to be able wash and launder the soft components and wipe the solid components to disinfect them.

The potential uptake of some innovative devices is, and will, continue to be restricted by these inherent industry requirements.

Alternatively, some of the devices where these features have been considered early in the design process, such as the 2 Laevo back exoskeletons (the flex and 2.57 devices), largely satisfy these criteria, were included in testing in this project and were found to be relevant for uptake in Australia.

5.6.1.2 Increasing use of soft & flexible components

Of the devices identified and procured for this project, some of the newer models use “soft” and or flexible levers and cables as well as soft padding and straps. That is, there are no long metal levers, which results in these devices being lighter, having a lower profile or spatial envelope around the wearers body, and being washable or wipeable on a daily basis using existing industry approaches to cleaning personal protective clothing and equipment.

The two stand out devices using soft or flexible components are the Ergosante Hapo Back and Hapo Front (ex MS) back and shoulder exoskeletons, and the Bioservo, Ironhand Bionic glove.

These types of devices were a surprising find, where, in their core design, they had departed from the common platform using solid levers, to use soft and/or flexible levers and cables. These key features inherently made them more useable within the red meat processing industry, delivering an immediate advantage for processors.

5.6.1.3 Exoskeletons that measure movement &/or force exertion

The final observed emerging trend for exoskeletons is the use of sensors to provide feedback to the assistance activation system that can and are also used to provide data about the nature of the jobs and tasks being performed. It is no overstatement to say that this presents a revolutionary new wave in the design and use of exoskeletons, which is a feature that has substantial relevance and potential benefit to the Australian red meat processing industry. Also, rather than just gather sensor-based data, one device provides the collation, analysis and presentation of these data relative to normative values. That is, for a given job or sequence of tasks, the system is able to define the physical nature of the work performed, in this instance the pattern of forces exerted, and then provide an analysis of this data relative to two validated assessment formats that use these data as their key inputs.

The only device that provides this data collection and analysis within those exoskeletons selected for this project is the Bioservo Ironhand bionic glove from Sweden. This feature extends the usefulness of this device from being, not only a remarkable device that provide configurable, dynamic and “smart” (AI influence) assistance to the wearer but converts this device into assessment tool that can gather useful data that can be used to analyse and better understand the nature of the jobs being performed and what employees performing this work are actually doing.

This direction in the incorporation of sensors into exoskeletons, regardless of whether they contribute to the activation of the device or are included simply to add value to the uptake and use of the device by gathering, collating and reporting data to the wearer and the organisation using these devices.

5.6.2 Issues specific to the meat processing industry

5.6.2.1 Limited access to emerging technologies in Australia

Australia’s location and small market size, in combination with the rapidly emerging nature of the exoskeleton industry and devices, resulted in it not being possible to establish contact with, or commitment from, existing manufacturers of exoskeletons considered to be relevant to the Australian red meat processing industry. Attempts to

procure some devices resulted in no responses from the manufacturer or them declining to provide devices into Australia because they had no distribution or support networks here. However, a key finding of this project was that this should not be an accepted barrier to gaining access to these technologies and the AMPC is encouraged to develop resources to discover technologies likely to be most relevant to the Australian meat processing industry to facilitate early uptake, and not wait for years before they become available within Australia.

A key outcome of this finding is the importance of the Australian meat processing industry establishing a presence globally as a potential innovative partner in the adoption, refinement and use of exoskeletons as one means of gaining early access to emerging technologies.

5.6.2.2 Generic nature of exoskeleton development

A key outcome of this project was that developers and manufactures of exoskeletons have appropriately focused on developing the capabilities of their technologies and devices. Presentation of these devices to the meat processing industry that pose the questions of whether they can be used in this environment and are they of use to processing jobs to manage the nature of their physical demands. The level of fine tuning or adaptation of these new and emerging technologies to the specific needs of industries does not seem to be an inherent feature of the development process. Instead, the devices are developed and bought to the market as generic devices with generic applications within industry.

This presents and ad hoc or opportunistic approach that may on occasions deliver suitable devices, as was discovered in this project. However, an approach that defines the nature and needs of the meat processing industry and targets the developers of a wide range of human assistance technologies would establish a more proactive footing to be able to engage with and deliver the benefits of these emerging technologies.

5.6.2.3 Protecting devices within the meat processing environment

Being able to provide barrier protection was identified as being a threshold requirement for the further testing of devices in Stage 3 of this project. Where a processor does not have suitable protective clothing for worn exoskeletons, such as fabric smocks and jackets, a need to provide device protection was identified.

An extensive search found that a plastic protective smock likely to be the most suitable option for employees wearing a shoulder or back exoskeleton. Note that protection for lower limb devices was not sought as these two devices were not included in further testing as the jobs that may benefit from this type of assistance were not identified with the meat processing industry.

Two hundred units of this smock were purchased from the manufacturer in New Zealand where they had been used for barrier protection of the Ergosante Hapo Back and Front devices (distributed by Exxovantage in New Zealand and Australia).

For the Ironhand bionic glove, these smocks were also seen as suitable protection for the small backpack, arm clips and cable core that runs from the base of the glove, along the wearer's arm, and over their shoulder an into the backpack. For this device, a nitrile glove and then a Kevlar or mesh glove was also worn.

No lower limb exoskeletons were recommended for in-processor testing so protection for the lower limb devices was not needed.

5.7 Defining the nature of meat processing jobs

The project revealed that the process of identifying a human assistance device, such as an exoskeleton, to assess its relevance to meat processing jobs could be streamlined and better informed if there is a detailed understanding of the job(s) for which assistance is sought and the circumstances of its likely use.

While red meat processors are acutely aware of the nature of each job performed relative to the processing, hygiene and safety requirements of the job, the detailed understanding of the sequence of tasks, the actions and movements performed, and variations of these, the type and level of force exerted and the duration and frequency of these elements is less, if at all, defined. In addition, an understanding of the cognitive elements of job and tasks, such as decision making and consideration about how to address variations in the presentation of a task, as well as the environmental elements that influence job and task performance, would also assist in defining the needs of people performing this work and the environment in which any assistive devices will be required to operate.

To pursue, and preferably drive, the greater engagement of the meat processing industry with the human assistance technology industry at a global level and get access to a range of innovative devices that may be incorporated into industry practice, this detailed understanding of the inherent nature of processing jobs and task should deliver a substantial benefit. This information would provide the basis of a dialogue with device developers and manufacturers where the meat processing industry should be able to provide an articulate detail of industry needs to better inform the development process.

The standardization of this knowledge base should enable comparison between different jobs and tasks across the industry, another feature to support the acceleration of engagement and effective use of these technologies.

6.0 Discussion and conclusions

The primary conclusion of this project is that, while the red meat processing industry has a wide range of criteria, including the work environment, that are likely to inherently limit the broad implementation of many exoskeletons, the uptake of exoskeletons and other human assistance technologies is highly compelling for the industry.

This project has confirmed that exoskeletons and other human assistance technologies have great potential to be useful in not only reducing the physical demands of many manual tasks performed within the industry and possibly improve the physical efficiency of operators, but how they may be used to better understand the nature of production and processing tasks that can be used to accelerate the development of greater mechanisation and automation across the industry.

However, the functions of these technologies need to be balanced with the ability to incorporate these devices into the day-to-day requirements of the industry for meat safety, wearer safety, operator and product hygiene, maintenance of product quality and production efficiency.

6.1 Engage with the revolution in human assistance technologies

This project has revealed that we are in the early stage of a major global revolution in how people will perform manual and physically demanding work. In addition to AI innovations and advances in robotics, the advances in human assistance technologies, including exoskeletons, has been exponential over the past 5 years.

This presents substantial opportunities to the Australian red meat processing industry and how the industry prepares and orientates itself to this revolution will determine how well it can engage with an exploit the rapid advances that are emerging.

The inherent nature of meat processing relies on people manually performing all, or the greater part of, all jobs within the processing environment. The pathway to greater mechanisation and eventual automation can be supported by the greater engagement with not just these emerging technologies, but with the developers of these technologies to ensure that the needs and circumstances of the meat processing industry are represented and accommodated in current and emerging designs.

Not only can human assistance technologies now provide highly creative and innovative ways of assisting human movement, but they are able to quantify what the person undertaking these movements is doing. This double benefit of assisting the person performing the work and being able to quantify the key attributes of this work and what they are doing to undertake work tasks has the potential to accelerate a wide array of technological advances in the design and performance of meat processing jobs. This has the potential to substantially reduce the industry's reliance of human hand/eye co-ordination capabilities and to reduce the overall level of human contribution to meat processing.

While this view may seem to be colourful and highly ambitious, the development potential for human assistance technologies appears to be substantial and the opportunity exists now for the meat processing industry to integrate its needs with these advances. However, attaining success and taking full advantage of these opportunities will require a focused, highly organised and strategic approach that is driven from within the industry.

6.2 Strategically position the red meat industry

A key conclusion of this project is for the industry to develop a dedicated reference group to co-ordinate this engagement and maximise the benefits across the whole industry. This will create a scale of application that will give the industry a loud voice to become the key driver of these innovations, rather than waiting for them to become available within Australia and hoping that they can be effectively implemented and have a sufficient level of impact in improving how work processes are performed.

This activity can be best driven and supported by an AMPC convened industry reference group that combines industry stakeholders and technical and technology experts. The recommended set up and operation of this reference group has been described within the recommendations in Section 7 below.

A strategic plan should be developed at the outset of this group's establishment. This reference group should take a global perspective, develop the required information to accurately define it requirements of human assistance technologies and then approach and engage with the developer of these technologies to identify and develop industry-based solutions. These technologies should include exoskeleton, sensing devices that quantify human activity, cobotic devices that can assist people to perform tasks and collaborative robots that can be used to perform components of a person's job within a process.

One of the first steps of this process should be the implementation of the devices assessed to be the most suitable for meat processing, as identified and recommended from this project (see Section 7 below).

7.0 Recommendations

7.1 Establish an industry reference group - human assistance technologies

A key recommendation of this project is to convene a specialist industry reference group to focus on the greater engagement with human assistance technologies across the Australian red meat processing industry. This reference group should consist of industry stakeholders within meat processing facilities and industry bodies, as well as technical experts. The primary purpose of this group would be to establish a framework for the co-ordination and oversight of the next steps in this engagement with current and emerging human assistance technologies for the industry. The group could be formed, led and operated by AMPC under its research and development umbrella and be established as an industry project for a set period of time (nominally 3 years). Human assistance technologies should include exoskeletons, cobotic devices and collaborative robots.

A fundamental objective of this group should be to move from the current “scattergun” approach of engaging with human assistance technologies where the consideration of new exoskeletons is largely opportunistic and based on manufacturers marketing devices to the industry. This results in a hit and miss approach which is largely passive where processors will test and evaluate devices to discover their potential. If they are successful then they may be implemented, if not they would simply not be purchased and introduced. A more active approach in defining industry needs and investigating and influencing the design of assistive devices to meet these needs would be fundamental to the activity of this reference group.

To achieve this, the group should seek to establish a global presence to identify and lobby for technologies that can best serve the short term needs of the industry to reduce the impact of physically demanding work on employees. The group should also work to pursue medium to longer term objectives of supporting the development of greater mechanisation and automation of work processes within the industry.

To convey innovations in the greater uptake of assistive technologies and an ongoing focus on greater mechanisation and automation, the reference group should develop a media capability and presence as the main method of demonstrating and promoting these improvements across the industry.

The establishment of this reference group and use of ongoing media to communicate its activities and achievements is also likely to establish a platform to promote innovation within clearly defined expectations.

7.2 Develop an industry road map to guide engagement with human assistance technologies

The industry reference group for the greater engagement with human assistance technologies should, at its outset, develop a road map that defines a pathway for the acceleration of the initial implementation of exoskeletons found to be of likely use for the industry within this project as well as the broader exploration, development and uptake of other human assistance technologies that will provide optimal benefit for the industry.

The short-term goals of this initiative should be to enhance the work capability of employees within meat processors, while the long-term goals should be to influence greater mechanisation and process automation by utilising advanced technologies and learning from any data generated and the experience of their application and use.

The key elements of the road map would be:

1. The development of referential standards and guidelines that define industry requirements. These would involve:
    a. Finalising and adopting the 5-step guideline for the evaluation and implementation of exoskeletons as the standard recommended approach for consideration and engagement with exoskeletons and other assistive devices within the meat processing environment *(see Section 7.3 below and Appendix 9.1 for guideline details)*.
    b. Implementing the exoskeletons recommended within this project using the method outlined in Step-5 of this guideline *(see more detail in Section 7.4 below)*.
    c. Developing a standardized referential dataset or library on the inherent physical activities performed within common meat processing jobs and tasks. This dataset would be based on the development of a standardized method of assessing and describing the physical demands of jobs and tasks. This dataset is likely to identify common features of the manual tasks performed within the jobs assessed, particularly if a standardized descriptive method is used. This information could present the opportunity

for human assistance, mechanisation and automation technologies to be developed and/or adapted to perform these common tasks or task features. This approach could have the potential to better match work tasks with assistance or mechanical replacement solutions *(see more detail in Section 7.5 below)*.

2. Establishing a priority list of the jobs that require most assistance, improvement and eventual greater mechanisation and automation. A specific strategy for each priority should be developed and implemented as a stand-alone project – although there will be common themes and overlap between each initiative.
3. Engaging with key developers and manufactures globally to identify current and emerging devices and to represent industry needs in the ongoing development of devices most relevant to the meat processing environment. A key feature of this engagement should be to promote and facilitate the inclusion of sensing devices, force and/or movement, into exoskeletons and other assistance devices. This would enhance the capability of these devices to deliver data on usage and task performance. In turn this data could be used to develop a deeper understanding of meat processing tasks to identify those tasks with the greatest opportunity for increased mechanisation and eventual automation and the features of these tasks that need to be replicated by these technologies *(see more detail in Section 7.6 below)*.
4. The ongoing communication of the activities and achievements of the reference group using nominated media platforms. Engagement with stakeholders should also be actively sought and promoted via this platform as well as through conventional industry meetings, presentations, workshops and conferences *(see more detail in Section 7.7 below)*.

7.3 Develop standardized job & task activity information & dataset

A knowledge base that defines and describes the understanding of the jobs and tasks performed within meat processing will be required. This could become a knowledge reference to inform the emerging exoskeleton, cobotic and collaborative robot industry about the nature of work performed in the industry and design requirements that must be achieved to deliver commercially viable and useful products. This reference could also be used to match the characteristics and assistance needs of jobs with the attributes of different assistive technologies to streamline the process of matching the best devices and solutions against the jobs that require them the most.

Establishing a platform for defining and describe job and task demands and attributes could help to define the precise nature of these actions used to perform these functions which could then be utilised to support and accelerate the pathway to greater mechanisation and eventual automation.

The industry reference group for greater engagement with human assistance technologies should oversee the development of this resource that standardizes a job and task assessment format that defines the physical, and predominantly manual, work tasks performed within the industry. This reference should describe the features of the postures, movements, forces exerted relative to the duration and frequency of common and/or challenging beef and sheep production, processing and ancillary jobs. This should involve the quantification of upper and lower limb, and trunk postures and movements for selected tasks. Movement sensors that are worn on an employee's body while performing their work can be used to generate this information.

This reference could also be correlated with injury data and anecdotal evidence across the industry, to help prioritise those types of work and jobs that would the priorities for improvement.

It may be possible to utilise existing exoskeleton devices to help gather this data. For example, the Ironhand glove can be configured in a way to quantify hand force exertion for any job where the glove is worn. A library of this

information could be used to better understand and compare hand force requirements for different jobs and contribute to the prioritization of the jobs for improvement.

7.4 Develop global relationships with technology developers

AMPC and the Australian red meat processing industry should avoid the adoption of a wait and see approach to engage with human assistance technologies where only those devices that marketed into the country are considered with the hope that they may have some positive effects to enhance the work capabilities of employees.

Instead, a more ambitious and assertive approach to go and find technologies and influence their design and development so they can be used within the meat processing environment and are well matched to the nature of the work performed is recommended. Using this approach, it should be possible to gain early access to emerging technologies as well as define to the human assistance technologies industry what the meat processing industry needs from its designs and devices. This industry globally is currently undergoing rapid development and expansion and there are opportunities for the meat processing industry to help drive and direct the development agenda.

The industry reference group for greater engagement with human assistive technologies should extend the foundation of work undertaken within this project in forging relationships with exoskeleton developers. As the objectives of the group are consolidated and greater definition of the needs of the red meat processing industry are established, group representatives should revisit these developers as well as identify and pursue additional technology providers to determine the capacities of their current and emerging technologies as well as communicating the needs of the meat industry in their current and future design.

The emphasis of this engagement should be on defining industry needs to the developers which should prioritise the functional requirements of being able to protect and clean devices as well as demonstrating the benefits of using sensors in devices, even if they are passive and do not influence the assistive mechanisms and collect data only

A goal of going out to this industry is to gain early access to emerging technologies to represent the meat processing industry needs in their design and functionality. This group should also approach the developers of existing relevant technologies to determine options of incorporating sensors into exoskeletons and other assistance technologies. This initiative has been developed as a response to the “discovery” of the Bioservo Ironhand bionic glove from Sweden where it took repeated approaches to Bioservo to convince them of the benefits of provided two sets of devices for trial with the Australian red meat processing industry. Their initial reluctance was overcome and enabled the early procurement of this innovative technology, well ahead of any intention of Bioservo to establish availability within Australia. It is highly likely that other technologies that can be procured ahead of their intended distribution to Australia to enable early engagement with and benefit from their uptake within the industry.

A benchmarking concept a developer of being able to successfully design and implement human assistance technologies that succeed within the meat processing industry, where these technologies are likely to be applied to a wide range of other complex, and less complex, environments should be actively promoted. This could be a significant motivation for technology developers to engage with the Australia red meat processing industry.

This discovery and outreach activity should include attendance at international conferences and trade shows as well as tours of developer/manufacturer locations and those processors internationally who have demonstrated advanced and successful engagement with human assistance technologies.

7.5 Develop a media platform to convey the work of the reference group

A media platform should be developed as the primary method of the industry reference group for greater engagement with human assistance technologies conveying its concepts, activities and outcomes. Modern media

platforms provide the capacity to communicate via graphical content, such a videos and commentary, as well as providing participants with the ability to interact and engage with the concepts and content. The ongoing use of this platform is anticipated to be the main driver in the greater engagement with industry stakeholders in their consideration and involvement with the new concepts and technologies what should be delivered by the activities of the reference group.

If the industry reference group is established as a key outcome of this project, the group's media approach and platform should be set up and resourced at the outset.

7.6 Adopt the 5-step guideline for evaluating & implementing exoskeletons

The 5-step guideline that describes considerations and strategies for the evaluation and possible implementation of exoskeletons, and other human assistance technologies, developed within this project should be reviewed, consolidated, finalised and adopted by AMPC as the primary reference for this activity across the meat processing industry. The reference should be a living document and be updated regularly based on its use and feedback.

This emphasis of this guideline document is on defining and promoting the needs of the red meat processing industry in the possible implementation of assistive devices. Accordingly, the guideline s0hould be promoted across the industry as a way of informing stakeholders of the emergence of exoskeletons and how the meat industry is planning to use a considered and co-ordinated approach to streamline the evaluation and engagement with these technologies. The emphasis of the guideline is to put the industry on the front foot to so only devices that meet the needs of the industry will be considered and utilised, rather than the industry simply trying to adapt generic technologies into this complex environment, which at times may be ambitious and under-represent the true potential of suitable technologies.

7.7 Implement exoskeletons recommended from this project

A number of exoskeletons from this project have been recommended for implementation, relative to the three implementation stages and criteria defined within the objectives of this project. These stages are:

1. Where the solution can be deployed now within industry.
2. Where the solution could be deployed now, with minor changes (for example wash down capability).
3. Where the solution could be evolved for future deployment.

The details of how each device should be implemented are describe below in each subsection. For each level of implementation of these exoskeletons, Step 5 of the 5-step guidelines for the evaluation and implementation of exoskeletons in the meat processing industry should be used as the primary reference and method. This should not only enable processors to pre-empt and accommodate potential short falls or limitations but should help to refine the detail of this reference for future use within the industry.

7.7.1 Implement selected exoskeletons – no changes

The following devices can be implemented with no changes or adaptations needed. However, the preparation, familiarisation, progressive implementation and monitoring strategies recommended in the 5-step guidelines, Step-5 Implementation, should be followed to optimise successful introduction of the device. Suggested considerations for each device have been described where required.

7.7.1.1 Apex (Herowear)

Device specific requirements

1. Fitting the device:
    a. The correct size of V-shaped rubber strap for the wearer must be chosen at the outset. This rubber strap is then fitted to the device **before** the wearer puts it on.
2. Adjustment:
    a. Check and practice the operation of the chest locking mechanism, where the tension of the rubber straps can be locked in place to emphasize support in a particular flexed trunk posture.
3. Protection:
    a. In production (slaughter) areas: Use a fabric smock over the top of the worn device. Check that the wearer can still activate and disengage the locking feature.
    b. In processing (boning and slicing) areas: Use a fabric smock over the top of the worn device. Check that the wearer can still activate and disengage the locking feature.
    c. In other areas: No protection required, although a fabric smock will help provide general protection for the device to limit cleaning requirements.
4. Cleaning:
    a. Before washing, remove the rubber strap and connect the waist and chest steps to reduce the risk of tangling during washing. Place the device in a protective fabric bag. Wash and dry the device while in this bag.
    b. After washing, re-attach the rubber strap to the device.
5. Maintenance:
    a. Regular visual checks for damage.
    b. Replace the rubber strap if it loses its elasticity or is damaged.
6. Jobs features targeted:
    a. Repeated forward reach and trunk inclination to help “hold” the trunk at the end of this movement and provide a small “lift assist” when moving back to an upright posture.
    b. Sustained forward inclined postures, including relatively low ranges of forward trunk flexion, to take advantage of the ability to adjust the tension on the rubber straps at the preferred trunk angle and maximise the “hold” of the device and support applied to the trunk when this posture is adopted.

7.7.1.2 Bionic Back (hTRIUS)

Device specific requirements

1. Fitting the device:
    a. No specific requirements.
2. Adjustment:
    a. Check and practice the operation of the hip loop straps that are pulled forward to increase device tension when the wearer adopts a flexed trunk posture, as well as the latches that release this tension when required.
3. Protection:
    a. In production (slaughter) areas: Use a fabric smock over the top of the worn device.
    b. In processing (boning and slicing) areas: Use a fabric smock over the top of the worn device.

c. In other areas: No protection required, although a fabric smock will help provide general protection for the device to limit cleaning requirements.

4. Cleaning:
   a. Before washing, release the activation tension straps and connect the waist and chest steps to reduce the risk of tangling during washing. Place the device in a protective fabric bag. Wash and dry the device while in this bag.
   b. After washing, no specific requirements.
5. Maintenance:
   a. Regular visual checks for damage.
6. Jobs features targeted:
   a. Repeated forward reach and trunk inclination to help “hold” the trunk at the end of this movement and provide a small “lift assist” when moving back to an upright posture.
   b. Sustained forward inclined postures, including relatively low ranges of forward trunk flexion, to take advantage of the ability to adjust the tension via the loop straps over the hips to maximise the “hold” of the device and support applied to the trunk at the selected angle.

7.7.1.3 Hapo Back (Ergosante)

Device specific requirements

1. Fitting the device:
   a. No specific requirements.
2. Adjustment:
   a. Check and practice the operation of the hip release latch so it is disengaged while walking and effective re-engaged when assistance is needed.
   b. Practice changing the level of assistance provided in trunk flexion, so the wearer is competent in making these adjustments.
3. Protection:
   a. In production (slaughter) areas: Use a fabric smock over the top of the worn device. Check that the wearer can still activate and disengage the locking feature.
   b. In processing (boning and slicing) areas: Use a fabric smock over the top of the worn device. Check that the wearer can still activate and disengage the locking feature.
   c. In other areas, an assessment of any needs for protection should be conducted. Note that protection may not be required, if there are no catching or other hazards resulting from the device being exposed and there is no specific requirement to protect it to keep it clean.
4. Cleaning:
   a. The whole unit can be dissembled and the soft components placed in a bag and washed in a conventional meat processing laundry with other employee PPC items. The rigid components can be wiped with sanitiser.
   b. After washing, reassemble the device.
5. Maintenance:
   a. Regular visual checks for damage.

6. Jobs features targeted:
    a. Repeated forward reach and trunk inclination to help “hold” the trunk at the end of this movement and provide a small “lift assist” when moving back to an upright posture.
    b. Sustained forward inclined postures, including relatively low ranges of forward trunk flexion, to take advantage of the ability to adjust the tension on the rubber straps at the preferred trunk angle and maximise the “hold” of the device and support applied to the trunk when this posture is adopted.

7.7.1.4 Hapo Front *(shoulder)* (Ergosante)

Device specific requirements

1. Fitting the device:
    a. Adjust the position of the struts on the pelvic plate to match the body size of the wearer **before** they put it on.
    b. Take care when applying the cuffs to the upper arm and forearm to prevent the strut from suddenly extending upwards if it is release before it is fixed around the upper limb and may flick the wearer’s eyes or face.
    c. Select the level of assistance needed by choosing and fitting the blue or yellow rods, according to the manufacturer’s instructions (the blue rods provide slightly more assistance than the yellow rods)
2. Adjustment:
    a. Check and practice the operation of the arm elevation assistance mechanism on each side so the wearer can easily increase and release this tension as needed.
3. Protection:
    a. In production (slaughter) areas: Use a fabric smock over the top of the worn device. Check that the wearer can still activate and disengage the locking feature.
    b. In processing (boning and slicing) areas: Use a fabric smock over the top of the worn device. Check that the wearer can still activate and disengage the locking feature.
    c. In other areas, an assessment of any needs for protection should be conducted. Note that protection may not be required, if there are no catching or other hazards resulting from the device being exposed and there is no specific requirement to protect it to keep it clean.
4. Cleaning:
    a. The whole unit can be dissembled and the soft components placed in a bag and washed in a conventional meat processing laundry with other employee PPC items. The rigid components can be wiped with sanitiser.
5. Maintenance:
    a. Regular visual checks for damage.
6. Jobs features targeted:
    a. Repeated shoulder elevation between 45 and 90 degrees (approximately). This can include movement of the elbows away from the side of the body (abduction) or in front of the body (flexion) or a combination of both movements.
    b. Sustained shoulder elevation within this range of movement.

c. Note different jobs may require different levels of assistance that are provided by the different strength and colour rods.

7.7.2 Implement selected exoskeletons – minor changes

The following devices can be implemented with a relatively low level of changes or preparation for extensive implementation. However, the preparation, familiarisation, progressive implementation and monitoring strategies recommended in the 5-step guidelines, Step-5 Implementation, should be followed to optimise successful introduction of the device. Suggested considerations for each device have been described where required

7.7.2.1 Leavo Flex (Laevo)

Minor changes required

1. Further practice within the meat processing environment is required to finalise the understanding as to how and where this device will be best used, relative to the range different levels of active assistance it provides and the different method of delivering assistance to the wearer.

Device specific requirements

1. Fitting the device:
   a. Adjustments to the harness should be made to match the size with the wearer and minimise changes once it is put on.
   b. The correct assistance cylinders (x2) should be chosen and inserted into the hip joint cavity before the device is put on. Follow the manufacturer's guidelines in selecting and inserting these components.
2. Adjustment:
   a. Check and practice the activation of the hip locking mechanism so it can be easily disengaged to facilitate walking.
   b. Check and practice the operation of the back flexion assistance/resistance mechanism on each side so the wearer can easily increase and release this tension as needed.
3. Protection:
   a. In production (slaughter) areas: Use a fabric smock over the top of the worn device. Check that the wearer can still activate and disengage the locking feature.
   b. In processing (boning and slicing) areas: Use a fabric smock over the top of the worn device. Check that the wearer can still activate and disengage the locking feature.
      c. In other areas, an assessment of any needs for protection should be conducted. Note that protection may not be required, if there are no catching or other hazards resulting from the device being exposed and there is no specific requirement to protect it to keep it clean.
4. Cleaning:
   a. Before washing, remove the soft pads and back plate.
   b. To wash the device, place the soft components in a fabric wash bag and machine wash them. Wipe the rigid components with a cloth and cleaning and/sanitising fluid.
   c. After washing, re-assemble the soft components so the device is ready for use.
5. Maintenance:

a. Regular visual checks for damage.

6. Jobs features targeted:
   a. Repeated forward reach and trunk inclination to help “hold” the trunk at the end of this movement and provide a small “lift assist” when moving back to an upright posture.
   b. Sustained forward inclined postures, including relatively low ranges of forward trunk flexion, to take advantage of the ability to adjust the tension on the rubber straps at the preferred trunk angle and maximise the “hold” of the device and support applied to the trunk when this posture is adopted.

7.7.2.2 Ironhand (Bioservo)

Minor changes required

1. Additional investigation into the range of different levels of assistance activation of this glove is required relative to the diverse range of different jobs that use of the glove is likely to assist. While the AI function is useful, fine tuning of the glove features should be developed to define the optimal configuration settings for different job types and the handling or different tools and meat products. For example, the different requirements for knife use that may occur between different slaughter and boning and slicing jobs as well as those when boning and slicing carcases that have been chilled for different period of time.
2. Further testing within the meat processing environment is required to finalise this more advanced level of understanding of this technology to ensure that it delivers maximum benefit in reducing repetitive and sustain grip force for meat processing jobs and tasks.

Device specific requirements

1. Fitting the device:
   a. Determine which hand that will be assisted (left or right).
   b. Choose correct size glove according to the manufacturer’s sizing guide.
   c. Choose whether the wearer should use a backpack or hip-pack to carry the Ironhand powerpack.
   d. Ensure the battery is fully charged before use and that a spare battery is charged and readily available for use when required.
   e. Care must be taken when removing the glove to progressively remove it rather than tug and pull it off at the fingers to prevent possible damage.
2. Adjustment:
   a. Check and practice the operation of the emergency shut down switch (worn on the chest strap).
   b. Check and practice the adjustment of the assistance level so the wearer is competent in its use.
3. Protection:
   a. Glove protection: This needs to be assessed relative to each area the glove will be used and the minimum hand protection required. However, within the slaughter, boning and slicing areas, it will not be possible to wear more than 2 gloves on top of the Ironhand glove. Typically, the first additional layer will be a waterproof glove and the second a cut resistant glove or a mesh glove. The highest level of protection recommended needs to be maintained wherever the Ironhand glove is to be used.

b. In production (slaughter) areas: Use a fabric smock over the top of the worn backpack or hip-pack should be worn. A plastic wrist gator or sleeve should be worn in wet areas. Check that the wearer can still activate and disengage emergency stop lever and the activation level while wearing PPC.
c. In processing (boning and slicing) areas: The same requirements as describe above within slaughter areas, except a wrist gator or sleeve will probably not be required.
d. In other areas: A protective glove should always be worn over the top of the Ironhand glove. A fabric smock or jacket may also be needed to protect the external cable core that extends between the glove and the backpack or hip-pack as well as these carrying packs.

4. Cleaning:
   a. Before washing, remove the power pack from the backpack and/or hip-pack. Remove the battery and recharge it. Disconnect the glove panel from the body pack. Loop the forearm and upper arm cable restraint bands over the glove cable to keep them together.
   b. Wash the glove, arm bands and backpack and/or hip-pack by placing them in a fabric bag. Wash and dry the glove and packs while in the bag using a conventional clothes washing machine and dryer.
   c. After washing, insert a new battery into the power pack, attached the glove interface to the power pack. Insert the power pack into the body pack or hip-pack so it ready for use.
5. Maintenance:
   a. Regular visual checks for damage.
   b. Recharge and replace batteries as required.
   c. Maintain connectivity between the gloves, the bodypack and the internet, usually via a local wireless network so data can always be uploaded.
   d. Ensure that data is downloaded and categorised as required. Note that the device always logs data, but it will be the choice of the processor as to whether it is downloaded, categorised and analysed.
6. Jobs features targeted:
   a. Any job requiring the repeated and/or sustained forceful grip of a tool or part of a carcase.
   (Note: Ensure that wearing the glove does not interfere with the wearer's ability to establish and maintain the required grasping actions and movements).

7.7.2.3 Paxeo thumb (Ottobock)

Minor changes required

1. Additional investigation into the effectiveness of the sizing range of these devices and how effective they are at assisting employees handle knives and any other equipment that is forcefully grasped.
2. Further testing within the meat processing environment is required to finalise the understanding of the suitability and use of these thumb splints.

Device specific requirements

1. Fitting the device:
   a. Choose whether a plain/smooth thumb pad device is to be worn or whether one with a thumb pad ridge is to be used.

b. The correct size should be selected for the wearer. They will need to put devices on to establish the most suitable fit.
c. If a firm but comfortable fit on the wearer's thumb cannot be established, they device should not be worn. If the device slides around when on the wearer's thumb it may not provide a sufficiently stable structure for the safe handling of knives or other tools or equipment.

2. Adjustment:
   a. No adjustment required as the device has a fixed size and shape.
3. Protection:
   a. In all areas: Use the required glove or gloves. Check that the device fits into all layers of glove protection. If it doesn't one layer may need to be left off, provided this does not compromise defined PPC requirements.
4. Cleaning:
   a. Wash the device in soap and warm water to clean it.
5. Maintenance:
   a. Regular visual checks for damage.
6. Jobs features targeted:
   a. Any job requiring the repeated and/or sustained forceful grip of a tool, such as a knife, or whizzard tool.

   (Note: Ensure that wearing the Paxeo thumb device does not interfere with the wearer's ability to establish and maintain the required grasping actions and movements).

7.7.3 Implement selected exoskeletons – improve for future deployment

Further consideration of improvements for the following devices are recommended before they can be implemented within the meat processing industry. If these features of these devices can be improved, then the preparation, familiarisation, progressive implementation and monitoring strategies recommended in the 5-step guidelines, Step-5 Implementation, should be followed to optimise successful introduction of the device. Suggested considerations for each device have been described where required

Given the product development experience and market prominence of Ottobock and Suit X (now owned by Ottobock), the following devices should be given the opportunity to determine if they can be adapted for use within the slaughter and/or boning and slicing areas within a meat processing facility.

7.7.3.1 Back X (Suit X/Ottobock)

Adapting the device for use within meat processing

Contact the manufacturer to determine if improvements to make it easier to clean the device on a daily basis to the required standards of a meat processor are or will be possible. If so, test and evaluate any improvements.

7.7.3.2 Paxeo Back (Ottobock)

Adapting the device for use within meat processing

Contact the manufacturer to determine if improvements to make it easier to clean the device on a daily basis to the required standards of a meat processor are or will be possible. If so, test and evaluate any improvements.

7.7.3.3 Shoulder X (Suit X/Ottobock)

Adapting the device for use within meat processing

Contact the manufacturer to determine if improvements to make it easier to clean the device on a daily basis to the required standards of a meat processor are or will be possible. If so, test and evaluate any improvements.

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9.0 Appendix

5-step guide - identification, evaluation & implementation of exoskeletons

9.1 Overview

Guidelines within a 5-step process that can be used across the red meat processing industry for the identification, evaluation testing and possible implementation of exoskeletons has been developed as a key outcome of this project. This evaluation process has been developed to assist the meat industry to critically assess devices as they become available and to understand their likely needs for the implementation of current and emerging worn assistive devices. Also, this guide seeks to assist meat processors to clearly define industry needs in the design and use of exoskeletons to manufacturers/distributors and to identify early in any evaluation process those variables that may exclude or limit the use of a device within this environment, regardless of its level of appeal or sophistication.

This 5-step process involves the following sequence of considerations:

Step 1 – Manufacturer/distributor evaluation

Evaluation of the capability of the manufacturer and/or distributor to deliver devices and assistance to support the assessment and possible implementation of their devices.

Step 2 – Meat processing industry criteria

Assessment of prospective exoskeleton devices against meat industry criteria to ensure that any device being considered can be safely used, cleaned and maintained in the varied and, at times, extreme environmental and risk mitigation conditions of this industry.

Step 3 – Exoskeleton initial assessment

The initial assessment of prospective devices to identify key features of fit, function and safety to then determine if procurement of devices for testing within the operational environment is likely to be worthwhile. Also, this level of assessment should support the early identification of any risks to food safety or the day-to-day commercial operation of the meat processor that may result from the uptake of these worn devices.

Step 4 – Exoskeleton fit, usability and operational testing

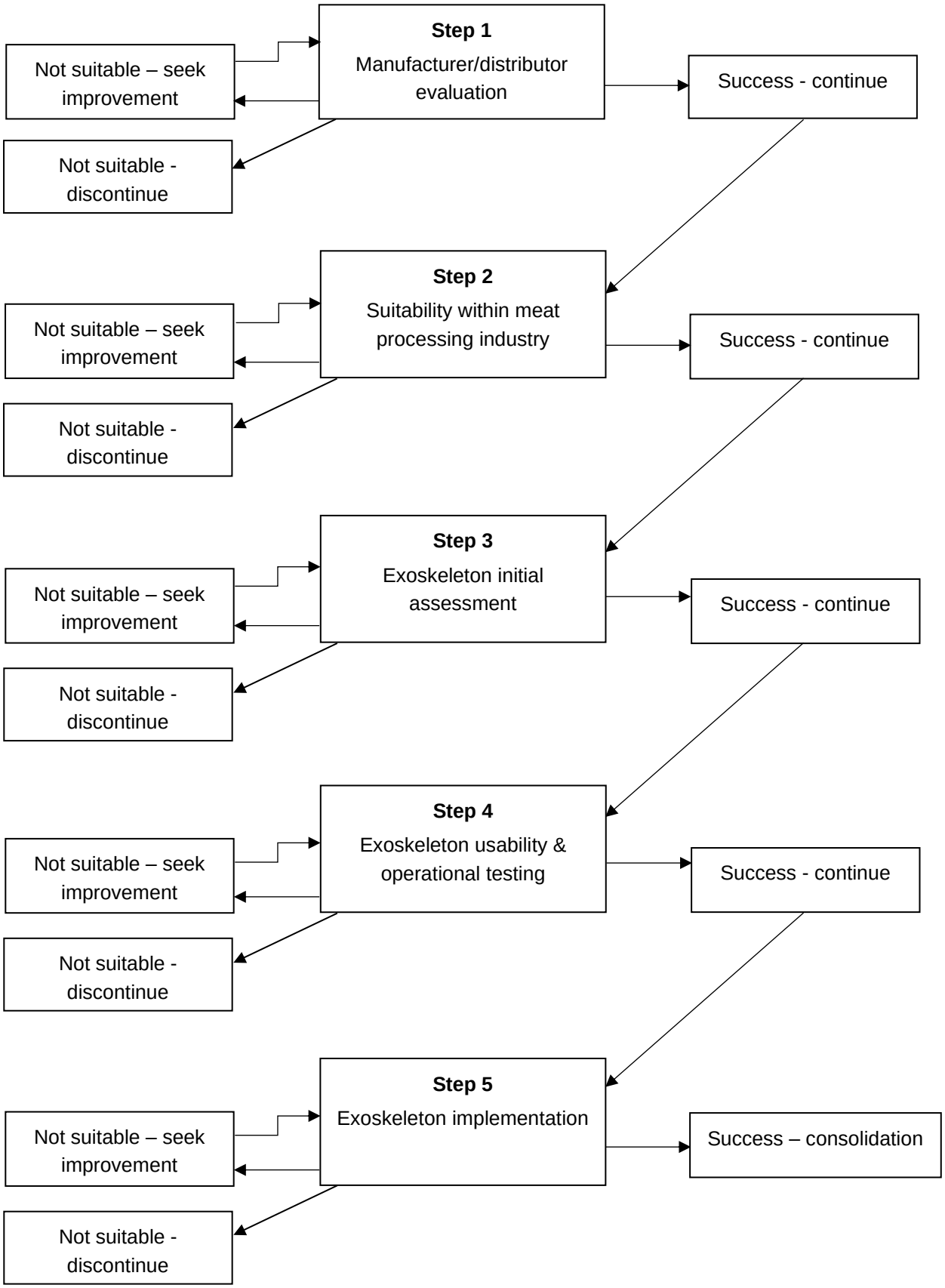
The procurement and operational testing of devices that have passed the criteria of the first three steps of this process. This testing should be conducted for the jobs where the type of assistance provided by a device is likely to be of benefit for employees and where other design improvements to reduce physical work demands are difficult, or not currently practicable, to achieve. All aspects of anticipated use, cleaning and maintenance of devices should be evaluated within this stage to determine if the device will be suitable to implement.

Step 5 – Exoskeleton implementation and consolidation

Devices that satisfy the assessment criteria of the first four steps of this evaluation process are likely to be suitable for implementation. The guidelines within Step 5 provide a comprehensive description of the approach and resources that should be used to optimise the likelihood of successful implementation. Activities within this step include ongoing review of uptake and effectiveness of the device to support its consolidation as a standard item of equipment used within a processor's facility.

The diagram below outlines each step of this evaluation process and how exclusion or progression of a manufacturer/distributor and/or device may proceed after their assessment at each of the first four stages of the

process The 5th and final step provides guidelines for the implementation of a chosen device based on the processor's progressive experience in assessing and trialling the device.



9.2 Summary

A key outcome of this AMPC exoskeleton project is the development of a 5-step process that can be used to evaluate the suitability of the equipment provider, the likely usability, effectiveness and usefulness of the device within the meat processing environment, as well as any limitations or risks, to then determine if it will be suitable for uptake and implementation.

The purpose of this process is to provide a format to assist the broad range of stakeholders to understand and consider the needs of this complex industry and to streamline the process of considering, testing and possibly implementing innovative assistive exoskeletons. It is important to highlight that this 5-step process seeks to not only identify devices that have potential to benefit the industry, but to eliminate those devices that are less likely to succeed within this environment. This process has been identified as being useful for the industry in a market that is rapidly expanding and presenting highly innovative devices to assist human function as well as devices that, regardless of their innovative functions, may not be useable within the red meat processing environment or present unacceptable secondary risks for the operation of the business.

This section provides a summary of the rationale and method for each of these 5 sequential steps of the process. These steps are:

Step 1 – Manufacturer/distributor evaluation.

Step 2 – Device suitability with the meat processing industry.

Step 3 – Exoskeleton initial evaluation.

Step 4 – Exoskeleton usability & operational testing.

Step 5 – Exoskeleton implementation.

The details of the assessment criteria and guideline strategies within each step of this process are described below in Section 3 of this Appendix (9.1).

Note that not all devices will need to be passed through this process. Over time, and as the market and uptake of exoskeletons matures, it is likely that certain devices will have a demonstrated capability to provide employee assistance and become accepted as standard “tools of trade”. However, because the exoskeleton industry is in an early and expanding phase of development and recognition, this guidance approach to assist the Australian red meat processing industry to critically evaluate manufacturers, suppliers and devices has been proposed. This approach should enable all stakeholders to focus their time and investment on devices that are most relevant to the industry and where their uptake and implementation is more likely to be successful, while limiting the resources that may be used to consider less suitable devices.

For example, Step 1 should be applied to new devices with no current Australian distributor as well as those with an existing distributor and a history of use of their device(s) in the meat processing or other industries that could be used as a reference. Step 2 enables devices to be assessed against industry criteria, where a highly functional device may not be suitable within this complex and highly regulated work environment. Application of steps 3 and 4 will assist in the consistent and objective evaluation of the capacities of potential devices and enable comparison of competing products. It is likely that more established devices within the meat industry may have already been through the first 3 or 4 steps of the process, and the processor may only need to focus on Step 5, to support the implementation and possible ongoing use of the of the device or devices.

9.2.1 Step 1 – Manufacturer/distributor evaluation

The evaluation of the supply and support capabilities of the manufacturer and/or distributor is the first step in this process. This is due to the rapid emergence of exoskeletons and human assistance devices globally and the acknowledgement that these developments are occurring in the northern hemisphere where a distributor may not be in place in Australia or where a local distributor may have limited or no experience within meat processing.

This project found numerous novel and truly innovative emerging devices for which there are no current plans for distribution within Australia. Rather than wait for the uptake of these devices to gain momentum to a level that they may become available within Australia in coming years, this project has identified a need and likely benefit for Australian industry to be on the front foot to facilitate the early discovery, evaluation, testing and possible implementation of such devices. In particular, where they may have a revolutionary impact in reducing the physical demands of meat processing work and enhancing processing efficiency and yield.

While this level of consideration may not seem to be relevant to all manufacturers and/or distributors, where there is an emerging range of devices becoming available within Australia via local distributors, given the novel nature and often unproven functionality and impact of devices, it is prudent to conduct a due diligence assessment of the manufacturers and/or distributors to underpin future investment in these technologies and their suppliers.

These criteria seek to obtain information about the manufacturer/distributor and their capacity to provide devices, their model for support services and their experience in providing their device(s) to the same or similar meat processors in other regions or countries.

These criteria about the manufacturer/distributor are:

1. About the manufacturer/distributor.
2. Current and planned presence in Australia.
3. Device types and range.
4. Evidence to support fit and device functionality claims.
5. Experience with the same or like industries.
6. Supporting the evaluation, uptake, testing and implementation of their devices.
7. Determining how to best protect worn devices during use.
8. Providing post implementation support.
9. Cost competitiveness of their devices.

If the manufacturer and/or distributor satisfy these criteria, or the testing and possible uptake of the device is very compelling and there is confidence that the distribution and support services can be developed in the short to medium term to a sufficient level, then the device evaluation process should progress to the next step.

If the manufacturer and/or distributor doesn't satisfy these criteria and can't demonstrate how they may be achieved, then proceeding with the manufacturer/distributor may need to cease but could be reconsidered at a future time if they can demonstrate the required improvements.

Note that for this AMPC "discovery" project, these criteria were not fully applied to manufacturers and/or distributors. Instead, these criteria were developed based on the experience within the project in working with manufacturers/distributors to bring these devices to Australia, where only a limited number were available during the project. At the outset of the project, only 20% of the devices identified as being suitable for testing were commercially available within Australia, and only 1 of the 19 devices procured had an existing distributor in the country. All other devices were purchased directly from the manufacturers overseas. While the presence of device

manufacturers/distributors in Australia is expanding, this evaluation of the manufacturer and/or distributor has been included as the 1st step of the process to ensure that there will be a suitable level of scrutiny over supply and product support for exoskeleton devices used by the industry.

9.2.2 Step 2 – Meat processing industry criteria

With the manufacturer and/or supplier capability being demonstrated through the Step 1 evaluation, the device(s) of interest should be considered and evaluated against the specific requirements of the red meat processing industry. These requirements and the meat industry processing environment and regulatory obligations can be very different to other manufacturing and processing environments. These meat industry criteria include the following factors:

1. Device name, details and type.
2. Device features and likely appeal to the meat processing industry.
3. Fit range to accommodate likely wearers.
4. Device protection, cleaning and maintenance.
5. Implications or limitations of use in meat processing environments.
6. Food safety and commercial risks.
7. Possible secondary hazards for users and others.

A key finding of this project was that devices that mostly use soft or flexible structures to provide assistance, such as elastic straps and cords and flexible struts and levers, have been found to be more likely to suit meat processing than devices that predominantly use rigid structures. This is because, in general, they are more likely to have a lower profile on the user's body and are more easily donned, adjusted, activated and doffed. In addition, the predominant use of soft or flexible components can make the device easier to protect and to clean after daily use, when compared to devices that have largely use rigid structures.

In addition, whether the device uses active power, typically electrical power, or passive assistance where springs and/or stretchable bands or cords are used is also relevant. Passive power usually represents a simpler design. However, while an active device is more likely to be inherently more complex and will require additional activity to maintain, some active devices, in addition to providing innovative features, use sensors to collect data on how the device is used. This feature of devices delivering data is emerging as a key growth area for the next wave of development of exoskeletons, particularly for industrial use where this feature is likely to expand the usefulness of assistive devices in the assessment and monitoring of physical work demands.

Based on the above observations, a general and simplified classification system for exoskeletons has been developed to assist potential users of this guide to quickly identify the likely adaptability of a device for use within the meat processing industry. The classification features are whether a device has predominantly soft or flexible components or mainly rigid components as well as whether it is activated by an active or passive power or energy source. The combinations of soft and passive were found to be more likely to be useable within meat processing. However, the combination of soft and active has appeal, particularly where the device can also measure its function and provide data on its use, although additional resources and organisation is needed to support powered devices. Devices with predominantly rigid structures may be less suited to uptake within the meat processing environment.

Other meat industry-based criteria are whether the sizing range will fit the workforce that might use the device, how it might be protected during use and cleaned after use and whether aspects of the nature of meat processing environments may exclude or limit the user of the device, such as use in extreme cold or wet environments.

In addition, any threats to food safety, such as components of the device that may dislodge and become embedded into meat products would pose an unacceptable commercial risk and is likely to exclude the use of device in production and processing areas.

If the device satisfies these fundamental meat processing industry criteria, or the manufacturer and/or distributor can take measures to eliminate or mitigate any of these limitations in the short to medium term, then the device evaluation process should progress to the next step. However, further testing shouldn't occur until any issues are rectified to prevent any problems of issues arising during testing.

If the device doesn't satisfy these criteria and the manufacturer and/or distributor are not able to offer any remedies, then proceeding with this device should cease and only be reconsidered at a future time if the required improvements can be demonstrated.

9.2.3 Step 3 – Exoskeleton initial assessment

The next step in the evaluation process focuses on the likelihood of good fit, the nature of the assistive function provided and the safety features of specific devices. In particular, whether the device can be comfortably fitted to the wide range of body sizes and shapes within the meat industry, what the device does to enhance a person's capability to perform manual red meat processing tasks and whether secondary hazards are likely to be present when wearing or handling the device. When considering the assistive functions of a device, it is important to also understand the physical demands of jobs and tasks performed across the industry to enable device functions to be matched with these demands.

This assessment should combine the initial assessment of devices via online or printed information in combination with any opportunity to obtain a device to see how it fits and works on a person and if any hazards may be present. Many, but not all, manufacturers/distributors will provide a device for review, or it may be possible to obtain one within the AMPC network.

The evaluation of a chosen device against core industry requirements within Step 2 is likely to exclude some devices because they don't, or can't, satisfy these criteria and be readily used within the industry. For those devices that pass the Stage 2, industry-based assessment, the Step 3 assessment criteria will evaluate the likely fit, function and safety of devices. A range of generic device fit, functionality and safety assessment criteria have been proposed (see below within this section). The primary outcome of this Step 3 assessment is to determine if procurement and testing of the device within operational settings, as defined in Step 4, is likely to be worthwhile to evaluate the device's potential for implementation.

One example of the Step 3 level of assessment would be the consideration of the range of movement requiring support for shoulder (and other) exoskeletons for meat processing jobs. The initial developmental emphasis for shoulder exoskeletons has, appropriately, been on providing assistance for workers where their hands are working above their head and shoulders repeatedly and/or for sustained periods of time. Many of these devices were designed with the automotive production industry in mind where these types of shoulder postures and movements are commonly used by employees when working within the cabin or under the vehicle body to assemble components. However, working within this higher range of shoulder movement is less common in the meat processing industry and a device that provides a configurable level of shoulder elevation assistance, nominally between 60 and 90 degrees, is more likely to be relevant to broad range of meat processing jobs in production (slaughter and carcase breakdown) and processing (boning, slicing and packing) areas.

The assessment criteria for this Step 3 initial evaluation of an exoskeleton that has been identified as possibly being beneficial for the meat processing industry include:

1. Detailed understanding of the exoskeleton being considered.
2. Evidence to support device fit and functionality claims.
3. Confirm meat processing jobs targeted and expected outcomes for use of the device.
4. Confirm fit range and anticipated comfort.
5. Device assistance function and range, how it is adjusted and the anticipated benefits.

6. Device data gathering and analysis on its function and use.
7. Identify and assess any apparent hazards or risks.
8. Confirm how the device will be protected during use.
9. Confirm how the device will be cleaned after use.
10. Confirm how the device will be maintained.

If each device being considered satisfies these requirements or the manufacturer and/or distributor can take measures to eliminate or mitigate any identified limitations in the short to medium term, then the device evaluation process should progress to the Step 4 assessment.

If the device doesn't satisfy these criteria and the manufacturer and/or distributor are not able to offer any remedies, then proceeding with this device should cease and only be reconsidered at a future time if they can demonstrate that the required improvements have been implemented.

9.2.4 Step 4 – Exoskeleton fit, usability & operational testing

The devices that have achieved the assessment criteria for the 3 previous evaluation steps should be procured from the manufacturer/distributor, who should also provide a comprehensive range of support, training, information and instruction with each item. It is likely that devices chosen for operational testing are likely to have a high potential for implementation. This would reflect the intent of the first 3 assessment steps in assisting processors to identify and filter out the least suitable devices for the industry so they can focus on those more likely to be useable.

Given this, any initial operational testing should be considered as the likely first step of implementation of the device and the detailed guidelines outlined in Section 3.4 (Step-4) following should be considered and applied. In particular, the logistics of where devices are to be donned by wearers, how they will be protected during use to minimise soiling and damage and how each device is to be cleaned and maintained after use should be developed and tested.

The rigorous evaluation of device fit, function and safety should be conducted at selected jobs at the processor facility using the following sequence of preparation, training, and evaluation activities and criteria.

1. Preparation for operational testing of the device.
2. Familiarisation and training.
3. Initial implementation.
4. Ongoing testing.
5. Data and feedback gathering.
6. Testing evaluation.

If each device being evaluated satisfies these usability, operational and safety criteria, then the processor should establish their level of demand for the device and consolidate the processes for training, progressive implementation, cleaning and maintenance to maximise the chance of each device being successfully utilised (see Step 5 below for implementation guidelines).

Any limitations identified during this level of evaluation should be taken to the manufacturer and/or distributor to see if the required improvement is possible. However, implementation of a device shouldn't occur until any issues are rectified. All local strategies regarding how the device will be worn, used, protected, cleaned and maintained should be in place at the outset of this operational level testing and their effectiveness reviewed as part of the evaluation process.

If the device doesn't satisfy the Step 4 assessment criteria and the manufacturer and/or distributor are not able to offer any remedies, then proceeding with this device should cease and only be reconsidered at a future time if they can demonstrate the required improvements. In addition, any limitations in the capacity of the meat processor to

provide and maintain the required level of support should be confronted to determine the viability of ongoing support for implementation of the device.

9.2.5 Step 5 – Exoskeleton implementation & consolidation

The previous procurement and testing step of the process should determine if an exoskeleton device is likely to be worthwhile implementing. This 5th and final step of the process provides guidance for the broader implementation of the device within one or more red meat processing facilities.

The following guidelines have been developed to assist meat processors to take advantage of the Step 4 evaluation experiences. Learning from the successes and any limitations of this part of the process should be used to establish the infrastructure and support needed to maximise the effectiveness of the device in reducing the physical work demands for employees and, where possible, develop new insights into the nature of the jobs performed to identify the next wave of improvements for further assistance, greater mechanisation and possible eventual automation. This later benefit will be possible for those devices that have embedded sensors that will provide ongoing data about task performance.

The emphasis of activity within this final implementation step of the process moves from the assessment and evaluation of an exoskeleton to the use of guidelines to help steer the medium to long-term use and effectiveness of the device.

In summary, these implementation guidelines are based on utilising information and feedback from the previous assessment steps of this process for a given exoskeleton, to refine and consolidate the training, resources, strategies and monitoring mechanisms needed to support the broader, effective implementation of the device. These guidelines are described to reflect the outcomes of the assessment factors that would have been considered within Step 4 of the assessment process. The key guideline categories to support the implementation of selected devices are:

1. Preparation for broad implementation of the device.
2. Familiarisation and training.
3. Initial implementation for new users.
4. Ongoing review of progress.
5. Consolidation

These guidelines should assist meat processors anticipate the broad range of issues that should be considered and accounted for when implementing exoskeleton devices. These guidelines acknowledge that the functionality of a device is only one of many factors that need to be accommodated, and that some of the more mundane aspects of donning, doffing, cleaning and maintaining devices may undermine the effective uptake of devices if they are not anticipated and well managed.

When introducing a new assistive device into the workplace, an ongoing process to monitor and review its performance over time is essential because there are no or limited long term case studies or experience of their use available for reference. A good relationship with the manufacturer/distributor is vital to enable processors to provide feedback and for these providers to continue to learn about industry needs and keep processors up to date with advances.

The successful outcomes of a device implementation strategy would be its ongoing use, with an understanding it helps to reduce employee work demands and where there is no or minimal disruption. This type of outcome would be similar to the use of a type of personal protective clothing (PPC) or equipment (PPE), where employees accept and value its use within their day-to-day work and simply don and use it as required.

9.3 Detailed assessment criteria & implementation guidelines

The detailed assessment criteria and guidance strategies at each step of consideration of the use of exoskeletons and their implementation are described below. These criteria and strategies have been developed from the findings of the literature review, information from exoskeleton manufacturers and distributors, the findings of the testing conducted within this assessment, and the feedback from meat processors involved in this project. They are not proposed as an exhaustive or definitive list of requirements. Instead, they have been developed as an initial range of considerations that are expected to assist and help fast-track the meat processing industry in critically evaluating and engaging with current and emerging exoskeletons and other human assistance devices. It is expected that these criteria and guidelines will be revised and expanded over time relative to industry experience and advances in the design of new devices as they become available.

9.3.1 Step 1 – Manufacturer/distributor evaluation

The following questions are designed to evaluate the viability of the manufacturer and/or distributor to be able to supply and support the exoskeleton(s) identified as being suitable for possible testing and implementation across the Australian Red Meat Processing industry. These questions are designed for existing and prospective suppliers of exoskeletons in Australia.

The categories for these evaluation criteria are described below.

1. About the manufacturer/distributor.
2. Current and planned presence in Australia.
3. Device types and range.
4. Evidence to support fit and device functionality claims.
5. Experience with the same or like industries.
6. Supporting the evaluation, uptake, testing and implementation of their devices.
7. Determining how to best protect worn devices during use.
8. Providing post implementation support.
9. Cost competitiveness of their devices.

9.3.1.1 About the manufacturer/distributor

1. Location and general information about the manufacturer/distributor.
2. Current presence and experience within the exoskeleton industry *(note: new and emerging devices should not be excluded on the basis of their limited history and experience).*

9.3.1.2 Current & planned presence in Australia

1. Which regions and countries do they currently operate within?
2. Does the manufacturer/distributor currently supply devices into Australia?
    a. If yes, describe their current distribution arrangements.
    b. If no, are there plans to supply devices into Australia?
        i. If yes, described the planned distribution arrangements, where they will be based and their planned service model relative to being able to supply the meat processing industry.
        ii. If no, consider whether the planned use of the device is likely to be viable with the manufacturer/distributor having a presence within Australia.
3. For distributors:
    a. Are they distributing this device in other regions or countries?

b. Do they have other devices or services that may be relevant to the meat processing industry? If so, provide details.

9.3.1.3 Device types & range

1. What devices does the manufacturer/distributor currently offer in Australia?
2. What body locations do these devices assist and how do they work?
3. How long have the current versions of these devices been available?
4. Are any upgrades or new models due in the near future?
5. Are/will the devices and services provided into Australia be the same as those provided in other regions and countries?
   a. If no, what will be different and why?
6. Are there other current or emerging devices that may fit within, and be of use to, the meat processing industry?
7. What categories are the devices currently, or soon to be, available (active or passive / soft or rigid)?

9.3.1.4 Evidence to support fit & device functionality claims

1. Can the manufacturer/distributor provide any evidence to support their claims of the functionality and effectiveness of their current or emerging devices?
   a. If yes, please provide these.
   b. If no, are any studies or assessments planned?
2. Can the manufacturer/distributor provide any evidence to demonstrate the quoted fit size and adjustment range to optimise comfort and functionality of their device(s) for wearers?
   a. If yes, please provide these.
   b. If no, are any studies or assessments planned?
3. Can the manufacturer/distributor provide information on how all components of their device(s) can be cleaned and washed after use, to the requirements of the meat processing industry?
4. Can the manufacturer/distributor provide any other information about their device(s) to assist in their evaluation?
   a. If yes, please provide this information.

9.3.1.5 Experience within the same or like industries

1. Have or does the manufacturer/distributor provide these devices and support services into the same or similar industries in these regions and countries?
   a. If yes, can they provide the details of, and introduction to, other meat processors that are currently using their devices in any of these locations?
   b. If yes, what have been the successes and biggest challenges in these processors using the device(s) provided?
2. Are these customers still using these devices? If not, provide details as to why?
3. What is the expected life of a device in the meat processing environment?
4. What is the uptake and current use of their device(s) in other industries?

9.3.1.6 Supporting the evaluation, uptake, testing & implementation of their devices

1. What approach do they take when first introducing one or more exoskeletons into a processing facility?
2. Do they provide devices for testing and evaluation?
   a. If yes, what are the conditions and details?
   b. If no, are there any alternative to purchasing a device that will enable it to be evaluated for possible use.

3. Do they have guidelines, training, information and instruction to support the progressive uptake of their devices to enable employees to build up their familiarity and tolerance in using them?
    a. If yes, provide details.
4. Can or do they provide assistance in matching device capability to the different jobs performed across the meat processing industry?

9.3.1.7 Determining how to best protect worn devices during use

1. What methods would the manufacturer/distributor recommend to protect the device when used within meat processing environments.
2. Does the manufacturer/distributor have experience in using these types of protection?
    a. If yes, provide details.
3. Can they provide any examples of protective clothing (PPC), or equipment (PPE) used to protect their device(s)?
    a. If yes, provide details.
4. Have any risk assessments been conducted to ensure that wearing of protective clothing or equipment does not introduce secondary hazards in meat processing environments?
    a. If yes, provide details.
    b. If no, the processor may need to conduct this risk assessment.

9.3.1.8 Providing post implementation support

1. What measures does the manufacturer/distributor take to provide post purchase and implementation support for their devices?
2. Does the manufacturer/distributor maintain adequate stock levels to minimise any downtime disruption that might occur if a device breaks or becomes unusable?
3. What time frame can be expected to provide new devices or replacement parts?
4. Are the devices covered by a warranty and what are the details of that coverage?

9.3.1.9 Cost competitiveness of their devices

1. What is the current price range to purchase these devices?
2. Are there charges for service and support or are these included in the purchase price?
3. Are pricing comparisons with competing like devices available?

Step 1 – Manufacturer/distributor evaluation outcome *(select one option):*

1. Is further investment in working with the manufacturer/distributor to identify and test possible exoskeletons worthwhile?
    a. If yes, summarise the reasons why and proceed to Step 2, the meat processing industry criteria assessment.
    b. If no, summarise the reasons why and cease engagement with them or get them to respond to determine if they can overcome any concerns.

9.3.2 Step 2 – Meat processing industry criteria

The red meat processing industry has specific requirements that must be accommodated by exoskeletons for viable ongoing use. A device may offer outstanding functionality, but it will not be usable if it creates uncontrollable risks to food safety and hygiene, the environment is too harsh for continued use of the device, or it introduces secondary hazards into this work environment.

The following considerations and criteria should enable a meat processing facility to evaluate exoskeletons against inherent requirements of the industry. These criteria are designed to not only determine if the device will be

compatible for use within a meat processing environment, but to provide a format for processors to be able to place a high onus of obligation on the manufacturer and/or distributor to demonstrate this level of compatibility and how any risks or limitations will be prevented or mitigated. These criteria are not exhaustive, and processors should add their own as they become apparent within the process.

The categories for these evaluation criteria are described below.

1. Device name, details and type.
2. Device features and likely appeal to the meat processing industry.
3. Fit range to accommodate likely wearers.
4. Device protection, cleaning and maintenance.
5. Implications or limitations of use in meat processing environments.
6. Food safety and commercial risks.
7. Possible secondary hazards for users and others.
8. Step 2 – meat processing industry criteria evaluation outcome .

9.3.2.1 Device name, details & type

1. Device name.
2. Body locations assisted.
3. Description of claimed device activation.
4. Device category:
    a. Soft (and flexible) or rigid.
    b. Active or passive activation power.

9.3.2.2 Device features & likely appeal to the meat processing industry

For each device, the following features of its use within the meat processing environment should be considered:

1. What does the device do to assist the person wearing it *(ie. what are the assistance features and how do they work)*?
2. Is the assistance device likely to be too complicated for use in meat processing environments?
    a. If yes, describe why?
    b. If no, describe why?
3. Are the device adjustment and assistance controls likely to be too awkward to use by a wearer of the device within the meat processing environment?
    a. If yes, describe why?
    (eg. Difficult to activate small control levers with a gloved hand , PPC worn may cover control devices over the top, performance of repetitive and short work cycles with limited breaks may limit options to adjust the device fit or activation)
    b. If no, describe why?
4. Describe the work areas and jobs most likely to be suited to the use of this device per the list of areas below *(note. more than one area and jobs can be selected).* For each meat processing job selected, confirm that the device assistance features align with the physical demands of the job. This may require an assessment of these physical demands.
    a. Yards (outdoor).
    b. Production areas (slaughter floor).
    c. Offal processing.
    d. Skin processing.
    e. Chillers.

f. Processing areas (boning and slicing).
g. Bagging and packing areas.
h. Value added areas.
i. Carton processing (load out).
j. Blast freezers.
k. Loading transportation vehicles (cartons and carcases).
l. Facility maintenance.
m. Facility and area cleaning.
n. Other areas.

9.3.2.3 Fit range to accommodate likely wearers

Meat processing is a diverse industry that employs a broad range of people of different body sizes and shapes. Increasingly females and new cultural groups who range from being very tall, short, broad and lean are employed. This requires devices to be able to fit a very broad cross section of this adult population.

1. Can the device manufacturer/distributor provide details about their sizing range and any limitations of fit that may occur with people due to their body size *(eg. height, girth, foot or hand size)*?
   a. If this information is available, is this sizing range likely to fit a sufficient range of employees at the meat processor who are likely to wear this device?
   b. If this information is not available, this device may not be suitable for further testing.

9.3.2.4 Device protection, cleaning & maintenance

1. Will the device wearer need to wear additional person protective clothing (PPC) or equipment (PPE) to create a shield or barrier to reduce exposure to blood, water and other contaminants and the risk of cross contamination?
   a. If yes, define the recommended PPC/PPE or, if this is not available, the type of PPC/PPE that is likely to be most effective, how it works to protect the device and where it can be purchased.
2. Describe how the device will be cleaned after use in the meat processing environment *(note: machine washing is the preferred method of cleaning soft components and rigid components can be wiped with a disinfectant)*.
3. Will this be satisfactory to clean all hard and soft components to the required standard on a daily basis?
   a. If yes, the device may be suitable for use within a meat processing environment.
   b. If no, this device may not be suitable for use in the areas of meat processing that require this level of hygiene to be maintained.
4. Describe how the device will be maintained on a daily and periodic basis *(include daily charging of batteries, or adjustment of settings to a defined level before the device is used)*.

9.3.2.5 Implications or limitations of use in meat processing environments

Consider if any of the following environmental factors are likely to affect the device or wearer during routine use.

1. Define the work environments where this device is likely to be used. Select all appropriate options *(note: more than one option can be selected).*
   a. Wet (direct exposure to water).
   b. Humid / moist.
   c. Exposure to blood, fat and body tissue.
   d. Cool temperatures *(2 to 8 degrees Celsius).*
   e. Extremely cold temperatures *(< minus 20 degrees Celsius).*
   f. Extremely hot external environments *(outdoor).*
   g. Exposure to dusty environments *(outdoor).*

2. Has the device been used in these environmental extremes before? If yes, provide details of successes and any failures.
3. Will the device consistently operate, be comfortable for wearers, and be durable in these environments?

9.3.2.6 Food safety & commercial risks

1. Is there a risk of small components becoming free and dropping onto product during processing or into product containers and cause contamination?
2. Are there any other features of this device(s) that may compromise produce and food safety?
3. Provide a detailed assessment of the device to identify any potential risks of it being used in this environment.

9.3.2.7 Possible secondary hazards for users & others

1. Will the wearing and use of this device and any required PPC/PPE in a meat processing facility create any secondary hazards or risks for:
    a. The user.
    b. Others working near them.
    c. The job being performed.
    d. Those required to clean and maintain the device.
        i. If yes to any of these, provide details the details of the hazard(s) and whether and how they can be eliminated or effectively controlled.
        ii. If they cannot be eliminated or controlled, this device may not be suitable for further consideration or testing.

Step 2 – Meat processing industry criteria evaluation outcome *(select one option):*

1. Based on the outcomes of the above assessments, is further investment in working with the manufacturer/distributor to identify and test possible exoskeletons worthwhile?
    a. If yes, summarise the reasons why and proceed to Step 3, the exoskeleton initial assessment.
    b. If no, summarise the reasons why and either cease engagement with them or arrange for them to follow up once they are able to satisfy these industry criteria.

9.3.3 Step 3 – Exoskeleton initial assessment

Once it is determined that one or more exoskeleton devices may be suitable for possible use within the meat processing environment, an initial evaluation of the device(s) should be conducted so those most likely to be of use are identified, understood and selected. Review of devices in Step 2 relative to the specific requirements of the red meat processing industry should exclude those devices that are not likely to be suitable within this environment. Accordingly, devices that pass the Step 2 evaluation process should then have the specific features of their likely fit, adjustment, effectiveness in assisting the wearer and general safety features assessed. This should enable a meat processor to finalise their selection for onsite testing (4th step) and possible implementation (5th step).

The intention of the Step 3 initial assessment of the exoskeleton(s) is to help meat processors to quickly identify and discard the devices least likely to be suited to, or useable, within the meat processing environment, while identifying and focusing on those devices most likely to be useable and useful.

The categories for these evaluation criteria are described below. A number of these relate to the same issues identified in the Step-2 Meat Processing Industry Criteria assessment, where greater details and confirmation of device suitability and how it would be tested within the workplace should now be described.

1. Detailed understanding of the exoskeleton being considered.
2. Evidence to support device fit and functionality claims.

3. Confirm meat processing jobs targeted and expected outcomes for use of the device.
4. Confirm fit range and anticipated comfort.
5. Device assistance function and range, how it is adjusted and the anticipated benefits.
6. Device data gathering and analysis on its function and use?
7. Identify and assess any apparent hazards or risks.
8. Confirm how the device will be protected during use.
9. Confirm how the device will be cleaned after use.
10. Confirm how the device will be maintained.

9.3.3.1 Detailed understanding of the exoskeleton being considered

1. Describe in detail the components of the device, relative to its fit and adjustment on the wearer as well as the features and functions of its components that anchor the device to the person's body and extend across it to provide assistance for postures and movements:
   a. The components that hold the device on the wearer's body *(eg. straps, cuffs, pads etc).*
   b. How the device is prepared for fitment to the wearer, how it is put on (donned) by the wearer, adjusted for optimum fit and removed (doffed) after use.
   c. The components that provide assistance to the wearer *(eg. springs, tensioned straps or cords, cables or small motors/mechanical devices)*.
   d. The assistance provided by the device, how the assistance components work, the ranges of movement over which they operate and how the level(s) of assistance can be adjusted to increase or lower their impact.
2. Confirmation whether the assistance device is likely to be too complicated for use in meat processing environments.
   a. If yes, describe why?
   b. If no, describe why?
3. Confirmation whether the device adjustment and assistance controls are likely to be too awkward to use by a wearer of the device within the meat processing environment.
   a. If yes, describe why?
   (eg. Difficult to activate small control levers with a gloved hand , PPC worn may cover control devices over the top, performance of repetitive and short work cycles with limited breaks may limit options to adjust the device fit or activation)
   b. If no, describe why?
4. Confirmation that any powered devices have a quick shut off feature that is readily accessible and usable for the wearer and co-workers or supervisors working near them.

9.3.3.2 Evidence to support device functionality claims

Can the manufacturer/distributor provide any:

1. Evidence or information to support their claims of the functionality and effectiveness of their current or emerging devices?
   a. If yes, please provide this information.
   b. If no, what is the basis of their claims of what the device does to assist a person are any studies or assessments planned?
2. Additional information to help in the evaluation of their device?
   a. If yes, please provide this information.
3. Information about other meat processors that have used or are currently using this device?
   a. If yes, please provide this information and their contact details.

9.3.3.3 Confirm meat processing jobs targeted & expected outcomes for use of the device

1. Confirm the jobs that appear to be most suitable for testing the device, within the nominated work areas. Select all appropriate options *(note. more than one option can be selected)*:
   a. Yards (outdoor).
   b. Production areas (slaughter floor).
   c. Offal processing.
   d. Skin processing.
   e. Chillers.
   f. Processing areas (boning and slicing).
   g. Bagging and packing areas.
   h. Value added areas.
   i. Carton processing (load out).
   j. Blast freezers.
   k. Loading transportation vehicles (cartons and carcases).
   l. Facility maintenance.
   m. Facility and area cleaning.
   n. Other areas.
2. Has an assessment of the physical demands of these jobs been conducted to define the postures, movements, force used and their duration and frequency to confirm that the device may be a suitable match?
3. Do the device assistance features align with the physical demands of the targeted meat processing jobs?
   a. If yes, describe the jobs most likely to be suited to the use of this device.
   b. If no, describe why the device functions do not align with meat industry jobs.
4. Has a risk assessment of these jobs been conducted?
5. Is use of this exoskeleton likely to be more suitable than design based (or other) improvements?
   a. If yes, describe the context as to why an exoskeleton may be the most suitable short to medium option to reduce work demands for these jobs.
   b. If no, describe what design improvements should be put in place to prevent the need to use the exoskeleton being considered.

9.3.3.4 Confirm fit range & anticipated comfort

9.3.3.4.1 Anticipated sizing range

1. Can the device manufacturer/distributor provide details about their sizing range and limitations of fit?
   a. If this information is available, will this sizing range fit the employees at the meat processor who are likely to wear this device?
   b. If this information is not available, this device may not be suitable for further testing.
2. Is there an absence of bias against gender with regard to fit and adjustment?
   a. If yes, please provide details.
3. Is the device likely to fit a sufficient range of the anticipated population of users?
   a. If no, please provide details.

9.3.3.4.2 Anticipated comfort when wearing the device for a whole shift

1. Do pads and straps appear to be a sufficient size to distribute load across the wearer's body?
   a. If no, please provide details.
2. Do any parts of the device appear to present a risk of placing excessive pressure on the wearer's body?
   a. If yes, please provide details.

9.3.3.4.3 Donning method

1. Are there any unusual requirements to prepare the device for donning or when putting it on?
    a. If yes, describe them.
2. Can the device be safely put on by the wearer without assistance?
    a. If no, please describe why.
3. Can the fit of the device be easily adjusted by the wear once donned to fine tune its fit, without assistance?
    a. If no, please describe why.

9.3.3.4.4 Wearing personal protective clothing (PPC)

1. Will the device be worn under or over existing PPC?
2. If worn under the wearer's clothing and PPC, will this inhibit access to and operation of the device?
    a. If yes, describe these details and any strategies that might be used to overcome them.
3. Will additional PPC need to be worn over the device to protect it?
    a. If yes, describe any additional PPC items and where they can be purchased if they are not already in use at the plant.
4. Will wearing the device result in any compromise to existing PPC requirement?
    a. If yes, described these details any strategies that might be used to overcome this.

9.3.3.4.5 Doffing method

1. Can the device be safely removed by the wearer without assistance?
    a. If no, please describe why.
2. Are there any unusual requirements to prepare the device for removal or when removing it?
    a. If yes, describe them.

9.3.3.5 Device assistance function, how it is adjusted & the anticipated benefits

General considerations for access to and adjustment of assistance controls are described below.

1. Does the adjustment control appear to be easily accessed by the wearer?
    a. If no, please describe why.
2. Does the adjustment control appear to be easily operated used by the wearer?
    a. If no, please describe why.
3. Is the wearer's PPC likely to reduce access to the controls and/or the ability of the wearer to manipulate them?
    a. If yes:
        i. Describe the details and whether and how this can be overcome.
        ii. Will this limit the ability of the wearer to be able to wear and use this device?
4. Do the controls appear to provide sufficient feedback to the wearer of the adjustment(s) made?
    a. If no:
        i. Describe the details and whether and how this can be overcome.
        ii. Will this limit the ability of the wearer to be able to wear and use this device?
5. For active devices that use a battery or other power source:
    a. What is the expected operational duration per battery?
    b. Will the wearer be able to change the battery during their main break, rather than having to change it while working?
    c. Is the method of changing the battery or batteries straightforward?
        i. If no, will this limit the ability of the wearer to be able to wear and use this device?

9.3.3.6 Device data gathering & analysis about its function and use

1. Does the device provide data on its function and use?
    a. If yes, describe how data is gathered, the data that is collected and how this can be used in operational testing.
2. Does the manufacturer provide data collation, analysis, storage and presentation features for this data?
    a. If yes, describe in detail, and how this can be used to assist operational testing.
3. Can data about an individual be de-identified so it can be used to describe device utilisation but does not reveal the identity of the wearer.
    a. If yes, describe how this is done.
4. How will these data be stored to maintain this confidentiality?
5. Is employee consent required for the collection, storage and use of data that originates from the device that they will be wearing?
    a. If yes, describe in detail, and the parameters of this consent (ie. any limitations as to how the data can be used).

9.3.3.7 Identify & assess any apparent hazards or risks

1. Describe any possible hazards or risks related to the use of this device for the wearer and those working near them.
2. Describe any possible hazards and risks related to the cleaning and maintenance of this device.

9.3.3.8 Confirm how the device will be protected during use

1. Describe any methods the manufacturer/distributor has recommended to protect the device when used within meat processing environments.
2. Does the manufacturer/distributor have experience in using these types of protection?
    a. If yes, please provide details.
3. Can they provide any examples of protective clothing or equipment used to protect their device(s)?
4. What follow up is needed to ensure that adequate device protection will be available for operational testing.
5. Have any risk assessments been conducted to ensure that wearing of protective clothing or equipment does not introduce secondary hazards in meat processing environments?
    a. If yes, please provide details.

9.3.3.9 Confirm how the device will be cleaned after use

9.3.3.9.1 Preparation for cleaning

1. Are any activities required to prepare the device for cleaning?
    a. If yes, describe these.
2. Are there any special methods of cleaning the device, such as using a bag to contain it when placed into a washing machine?
    a. If yes, describe them.

9.3.3.9.2 Cleaning the device after use

1. Describe in detail the process that will be used to clean the device, so it is ready for the operator on their next working day. For example:
    a. Is the wearer required to prepare the device for cleaning?
    b. Where will the device be deposited for cleaning?
    c. How will the device be cleaned?

9.3.3.9.3 Preparation of the device for wearing (after cleaning)

1. Will the cleaners be required to reassemble the device after cleaning to ensure that it is ready for use?

   a. If no, who will do this and where will it be done so the device is always read for next day use?
2. Where will the device be placed so it is ready for use by the wearer on their next working day?

9.3.3.10 Confirm how the device will be maintained

1. Describe in detail the process that will need to be used to maintain the device on a daily, weekly and monthly basis. For example:
   a. For active devices, who is required to recharge any batteries, so they are fully charged for their next working day?
   b. Where will charging occur?
   c. Where will batteries be placed so they are ready for use by the wearer on their next working day?
   d. Is an additional supply of charged batteries required to ensure that power supply is always available?
      i. If yes, who will be responsible for this and where will they be charged and stored.
   e. What checking of the components of the device is required to ensure that it is safe to use?
   f. What will the process be to replace damaged or broken components?
   g. Will this prevent the device from being worn if repair is required?

Step 3 – Exoskeleton initial assessment outcome (select one option):

1. Based on the outcomes of the Step 3 assessment above, is the device being assessed suitable for further testing (Step 4)?
   a. If yes, summarise the reasons why, the expected outcomes, any conditions or strategies needed to support further testing and proceed to Step 4, the exoskeleton fit, usability and operational testing.
   b. If no, summarise the reasons why and cease engagement with the manufacturer/distributor or arrange for follow up once they are able to satisfy these initial assessment criteria.

9.3.4 Step 4 – Exoskeleton fit, usability & operational testing

Having selected an exoskeleton found to be suitable for use within the meat processing industry, that appears to provide useful assistance for postures and movements when performing selected jobs, and that is likely to deliver good fit and comfort for users, the next recommended step is to obtain and test one or more devices in the workplace to determine if it should be implemented.

The following categories of guidelines and assessment criteria for exoskeleton testing have been developed to assist meat processors with this workplace-based evaluation of a device:

1. Preparation for operational testing of the device.
2. Familiarisation and training.
3. Initial implementation.
4. Ongoing testing.
5. Data and feedback.
6. Testing evaluation.
7. Determination of implementation of the device.

9.3.4.1 Preparation for operational testing of the device

1. Establish an exoskeleton evaluation project co-ordinator (if one hasn't already been chosen).
2. Confirm the jobs for which testing of the exoskeleton will be conducted.
3. Confirm the suitability of using an exoskeleton to reduce physical work demands for these jobs (via any previous assessment).
4. Procure the required number of devices for testing.
5. Establish the operational testing time frame for the following sequence of activities:
   a. Preparation.

b. Familiarisation and training.
c. Initial implementation.
d. Ongoing testing.
e. Data and feedback gathering.
f. Testing evaluation.
g. Determination of implementation of the device.

6. Identify the participant group who will wear the device for testing *(select a representative cross section of employees who perform the targeted jobs, considering skill level and body size representation)*.
7. Gather information about the device to support training and instruction that should include:
   a. Assessment information obtained to date within this 5-step evaluation process.
   b. Training support material from the manufacturer/distributor:
      i. Online, printed and video instructions.
      ii. Develop any additional guidance information if required? For example, whether a “simple” 1-page visual guide for donning, adjusting and using the device is to be made available for employees to follow when they first use the device.
8. Confirm if the manufacture/distributor provides on-site training and support and, if so, organise a schedule and the resources for this training.
9. Finalise the operational testing evaluation process and content. This should include:
   a. Direct feedback from devices users at any time.
   b. Standard feedback surveys for users and other stakeholders, such as supervisors, to complete at set periods within the testing schedule (see Section 3.4.5 below).
   c. Quantified data where available. For example, data directly from the device being testing if that is available.
10. Device protection:
    a. Implement strategies for the consistent protection of the exoskeleton during all phases of operational testing per the device protection considerations previously described in Section 3.3.8 above.
    b. In addition, also consider:
       i. If the device needs to be protected only during operational use.
       ii. Whether the whole device or only part(s) of it requires protection.
       iii. Will existing PPC be sufficient?
       iv. Will additional PPC or another type of barrier be required?
    c. Are there any risks present that may be associated with wearing this protective clothing?
       i. If yes, describe these, any risk elimination or mitigation strategies and how it will be safe for the employee to wear protective layers.
11. Device cleaning:
    a. Implement strategies for the consistent cleaning of the exoskeleton during all phases of operational testing, per the cleaning considerations previously described in Section 3.3.9 above.
    b. Also, define the specific method for cleaning all soft and rigid components of the device. For example:
       i. Is a soft wash bag needed when washing soft components?
       ii. Can soft components be washed at high temperatures?
       iii. What cleaning or disinfectant agent will be used to wipe down rigid components?
12. Device maintenance:
    a. Implement strategies for the timely and consistent maintenance of the exoskeleton during all phases of operational testing, per the maintenance considerations previously described in Section 3.3.10 above.
    b. In addition, also consider:
       i. Has the manufacturer specified a method of inspection for maintenance?

ii. Has the manufacturer described maintenance methods for specific components and/or functions and the time frames for any of these checks? For example, checking wear and tear on cuffs, cables, levers or rigid components that bear highest levels of force?

c. Maintain a record of maintenance checks and any device defects or requirements for maintenance and repair during the testing and evaluation period.

13. Describe the expected daily sequence of use for each device and employee who will wear it and ensure that each of these steps is organised and understood by all stakeholders to optimise the success of the testing process. For jobs performed within production and processing areas, this sequence is likely to include the following tasks and activities:
    a. Collect the device from storage after cleaning.
    b. Don usual PPC/PPE.
    c. Don the exoskeleton before moving through the washroom unless the device is worn on the employees' hands, to ensure that their hands can be washed. Devices worn on the hands should be donned after the washroom.
    d. Adjust the device for fit.
    e. Set device so walking is not inhibited (back and lower limb devices).
    f. Don additional device PPC if required (at the appropriate work location).
    g. Walk to the washroom.
    h. Wash hands and boots.
    i. Walk to the knife preparation area.
    j. Prepare knives (or other work tools/equipment) for use.
    k. Don the device and relevant PPC once ready to move to the work area, if not donned before the washroom.
    l. Walk to the work area.
    m. Prepare to commence the job in the work area, if required.
    n. If not already turned on, activate the device assistance so it is ready to use when the job commences.
    o. Commence work.
    p. If moving to another job within a rotation, change the setting according to any pre-determined instructions.
    q. Cease work and walk to short breaks as needed, repeating device inhibition if needed, and hand washing and drying procedures. Determine if the device should be removed or remain worn during shorter smoko breaks.
    r. For the longer meal break, cease work and walk to break room as needed, repeating device inhibition if needed, and hand washing and drying procedures. Consider removing the device for the longer meal break? Note that during initial use of the device, while the duration of daily use is being built up, the wearer may need to take the device off at any of these breaks, until they eventually build up to whole of shift use, or any other defined period of maximum use per day.
    s. Cease work at the end of the shift.
    t. Walk to the change room, repeating device inhibition if needed, and hand washing and drying procedures.
    u. Doff all PPC.
    v. Doff the device.
    w. Prepare the exoskeleton for cleaning per instructions. For example, remove soft or flexible components and place them in a soft bag for washing. Isolate rigid components that will be wiped to clean them.
    x. Describe the wearer experience in using the device that day, using a brief survey. For example:
        i. Was the device comfortable to wear? If no, describe any area(s) of discomfort and how this can be relieved.
        ii. Did the device work? If no, what can be done better? If yes, what were the perceived benefits?

iii. Were there any issues that need to be addressed/fixed? If so, what were they and how will they be addressed?
iv. Is the PPC coverage adequate? If no, what additional protection is required and how will this be organised?
v. Describe (rate) thermal comfort when wearing the device.
vi. Is the device too bulky when worn?
vii. Is the assistance mechanism easily adjusted (up and down)?

y. Deliver the device (components) for cleaning.

14. Device storage:
    a. Storage before use – describe wear and how the device is stored after cleaning, where it is ready for use.
    b. Storage after use – describe where and how the device should be delivered after use so it can be cleaned. For example, where is the device reassembled and who will do this.

9.3.4.2 Familiarisation & training

1. Inform participants that wearing the device during testing is voluntary and there will be no punitive measures if they choose not to wear the device.
2. Provide familiarization and training sessions to participants and stakeholders (eg. supervisors).
3. Emphasize the knowledge of the physical demands of the targeted jobs, the expected assistive capacity of the device to reduce these demands, the anticipated outcomes of this project and how it will be evaluated.
4. Learn how to fit the device onto each participant:
    a. Choose or set the size to match the size of the participant.
    b. Prepare the device for fitment to the participant wearer per the manufacturers or additional instructions.
    c. Don the device and adjust for optimal fit. This should achieve a high level of comfort and not result in the exertion of localised pressure of any area on the wearer's body through the expect range of postures and movements.
    d. Confirm that an optimal fit is achievable and the settings to achieve that for each participant.
    e. If it is not possible to achieve optimal fit of the device on a participant, determine why, inform the manufacturer/distributor and inform the participant that it will not be possible for them to continue with the testing. Recruit another replacement participant if required.
    f. Record the donning and fit adjustment process for each participant wearer so they can refer to that when putting it on in future.
    g. Each participant should practice and demonstrate preparing the device for fitment, donning it and then adjusting it for optimal fit until they can demonstrate competency in achieving a consistently high quality of fit of the device.
    h. Doffing of the device and preparing it for cleaning should also be demonstrated and documented and each participant trained so they consistently remove it in the same, safe manner.
5. Learn how to adjust the device during non-operational activities to avoid unnecessary restrictions:
    a. For example, with some devices, such as back exoskeletons, the anchoring around the wearer's thighs will restrict their ability to walk unrestricted. This will require the device settings to be adjusted to de-activate the assistance function and allow other movements, such as walking to be undertaken. Once the wearer and device are ready to perform the job, the device needs to be reactivated. For example, for back exoskeletons, the hip joint may need to be deactivated so it moves freely during walking.
6. Learn how to adjust the assistance function(s) of the device for each participant:
    a. The assistance function(s) and settings should be clearly described.
    b. Before donning the device, instruct participants in the activation features of the device, what they do and how the settings are raised or lowered.
    c. Don the device with the assistance feature turned off, deactivated or set to its lowest level.

d. Once the device has been fitted for optimal comfort and “anchoring” on the wearers body, they should practice adjusting the control(s) to vary the setting levels up and down until they are competent.
e. If the device uses active power, the participant should learn and practice how to shut it off quickly so it can be promptly disabled if required.
f. The participant’s immediate co-workers and supervisors may also need to learn how to quickly deactivate the device.
g. Practice the range of postures and movements typically used on the job(s) being tested and estimate the level of assistance that may be required. This should be conservative, and it is preferred that the testing at the job location starts with lower levels of assistance to enable the participant to adapt to wearing and using the device and to reduce inadvertent hazards or risks.
h. Use of the participant’s work tools and equipment that are normally utilised should also be tested before moving to the operational area, as much as practicable.
i. Contact the manufacturer/distributor if any issues of concern arise to either develop a solution. If this is not possible cease use of the device to prevent exposure to any risks.

9.3.4.3 Initial implementation

1. Establish the testing method and timeframe for the device and selected jobs and commence the initial implementation according to this method and schedule (see below).
2. Follow the method of moving from training-based testing to operational testing as outlined in Section 3.4.1 point 13 above.
3. The following approach to the initial implementation of the device in operational areas is recommended:
   a. The participant should be able to cease wearing the device at any time and for any reason, without consequence to them. The detail of this circumstance should be recorded, in confidence, to understand any factors that should be considered for the safe and functional use of the device by other participants.
   b. The participant should promptly report any hazards, risks, concerns or discomfort so the project co-ordinator can rectify the issue(s) or cease use of the device until any issues can be resolved.
   c. Establish a graduated program for wearing the device to enable each participant to build up their level of use over a period of one to two weeks, and longer if required.
      i. For example, not more than 2 hours of consecutive wearing for the first 2 to 3 days, increasing by a 2-hour period with each increment until the participant feels comfortable wearing the device for a normal shift period, including any regular overtime.
      ii. This graduated wearing of the device should rely on feedback from the participant and a slower rate of uptake should be used if required. A more rapid uptake of the device should only occur if there is a clear indication that it is safe to do so, and that the participant approves.
   d. The range of jobs to be performed, and the variations of these jobs as different products are processed, should be defined.
   e. The level of activation of the device should only be increased once the participant is comfortable wearing the device and feels competent wearing it while performing all jobs.
   f. The level of activation of the device should be co-ordinated between the project co-ordinator and participant, and it should only be increased to levels that the participant approves of.
   g. The use of increased levels of assistance should be tested for 10 to 15 minutes before confirming that this level can be maintained.
   h. The participant should reduce the level of assistance provided by the device if needed at any time and for any reason.
   i. A record of changes in the level of assistance engaged and the impact on the participants performance of the job should be kept on a daily basis until a pattern of use that is considered to be useful and safe for the participant is established.
   j. Records on consistent assistance settings for specific jobs should also be conducted.

4. Once the participants are confident in using the device and setting the assistance levels, they should be encouraged to conservatively try different levels for different jobs or variations of the same job (eg. When boning or slicing product that has been in the chiller for several days, when it is harder and will require greater force when applying the knife, so a proportionally higher level of assistance may be helpful).
5. A brief, standardised survey of participants' daily level of use of the device, the jobs performed, the activation levels used, the device comfort, perceived usefulness and any observed hazards, risks of concerns should be recorded at the end of every shift. This record should be provided to the project co-ordinator at the end of every day to ensure this information is available for review during and at the end of the testing period.
6. Once the participant has established a consistent pattern of use and activation settings for the device. They should perform the same jobs for a day, or part of a day, without wearing the device. Their observations of the differences in their level of effort exerted to perform the same jobs should be recorded as one way of assessing if the device seems to provide any benefit.
7. For any devices that collect data during use, configure the settings and the data to be collected, and how this will be downloaded, labelled, categorised, collated, analysed and reported as part of the device evaluation. Ensure that this data is captured and catalogued on daily basis.
8. For highly complex assistive devices, such as the Bioservo IronHand glove, additional pre-testing of the device is likely to be required to establish the best settings to use for different manual jobs. This is because the device is likely to have multiple levels of configuration for its assistive functions, making it more complex to set up, in addition to the use of Artificial Intelligence features, that will automatically and dynamically adjust assistance settings based on the hand activity patterns demonstrated by the wearer.

9.3.4.4 Ongoing testing

1. Ongoing testing should be conducted once the participant is able to wear the device for up to an entire shift and they are able to vary the settings according to their preference for the range of jobs and tasks that they usually perform.
2. The duration of ongoing testing will need to be established by the processor. This type of testing is important to help decide about whether the device should be implemented on a full time basis, so a minimum nominal period of up to 2 to 3 weeks for ongoing testing for each participant is suggested.
3. The same survey applied during initial testing should be recorded at the end of each week during the ongoing testing phase. Responses within this survey that identify the need for improvements should be promptly implemented and, if this is not possible, the participant should stop wearing the device until the required improvements are addressed.
4. Any device based data gathering, collation and analysis should also continue to be obtained during this ongoing testing phase.

9.3.4.5 Data & feedback

1. During the initial testing phase, participants should complete a daily survey of comfort, device effectiveness and impact and general progress.
2. During ongoing testing, this survey should be completed at the end of every week.
3. At the end of each week during both phases, feedback from supervisors and other relevant stakeholders should also be obtained to enable them to progressively share their views and so they are engaged during the project. Supervisor surveys should include questions as to whether use of the device is disruptive, inconvenient or poses any threats to safety and whether use of the device contributions to overall productivity and yield. That is, if there a perceived benefit in using the device, obtain details of these benefits?

4. Any data provided by the device should continue to be collected and downloaded on a daily basis. The analysis of this data should also occur as a parallel activity and the involvement with the manufacturer/distributor for this analysis is strongly encouraged.
5. For each different job where the device is worn and tested, write down the daily sequence of activities to don, use, doff and clean the devices, as described in Section 3.4.1 Point 13 above. This reference can be used to fast track use of the device if it is implemented after the Step 4 operational testing phase.
6. At the end of the evaluation process, develop a “tips and traps” reference sheet for new users of the device that can be used to help them fast track their learning about the safe and effective use of the device.

9.3.4.6 Testing evaluation

1. All feedback and data should be collated and analysed to finalise the evaluation of the device.
2. A range of general questions should also be considered in the overall evaluation of the use and testing of the exoskeleton device, such as:
   a. Did the device do what the manufacturer/distributor said it would do?
   b. Did the device performance fall below, match or exceed expectations of its impact on reducing physical work demands for employees?
   c. Is the device suitable for use in this environment?
3. Were there any issues or limitations regarding:
   a. Fitting the device to employees?
   b. Employees wearing the device for an entire shift and on a daily basis?
   c. Controlling and using the activation of the assistance features of the device?
   d. The type and level of assistance provided by the device.
   e. How was the device protected, whether this is satisfactory or improvements are required?
   f. How was the device cleaned, whether this is satisfactory or improvements are required?
   g. How was maintenance of the device conducted, whether this is satisfactory or improvements are required?
4. Were any hazards identified in the use of the device at any stage?
   a. If yes, describe them in detail and whether and how any associated risks were controlled. If any risks cannot be satisfactorily controlled after contact with the manufacturer/distributor, then use of the device should cease or be restricted to avoid exposure to any risks.

Step 4 – Exoskeleton fit, usability & operational testing outcome

1. Based on the outcomes of the Step 4 operational testing, is the device suitable for implementation (Step 5)?
   a. If yes, summarise the reasons why, the jobs for which this device will be worn, any conditions or strategies needed to support implementation and proceed to Step 5, exoskeleton implementation and consolidation.
   b. If no, summarise the reasons why and either cease further investigation into this device or arrange for follow up with the manufacturer/distributor and, if they are able to satisfy any limitations found during the operational testing phase, reconsider further testing to confirm it is suitable for implementation.
2. Is the device likely to be suitable in other areas and jobs within the processing facility?
   a. If yes, identify those areas and jobs and repeat Steps 3 and 4 to test and evaluate its likely usefulness and effectiveness in reducing physical work demands and enhancing efficiency.

9.3.5 Step 5 – Exoskeleton implementation & consolidation

The Step 5 implementation guidelines are based on utilising information and feedback from the previous assessment steps of this process for a given exoskeleton, to refine and consolidate the training, resources, strategies and monitoring mechanisms needed to support the broader, effective implementation of the device. These guidelines are

described to reflect the outcomes of the assessment factors that would have been considered within Step 4 of the assessment process. The key guideline categories to support the implementation of selected devices are:

1. Preparation for broad implementation of the device.
2. Familiarisation and training.
3. Initial implementation for new users.
4. Ongoing review of progress.
5. Consolidation.

9.3.5.1 Preparation for broad implementation of the device

1. Establish device implementation leaders within the target area(s).
2. Confirm the jobs for which the exoskeleton will be used.
3. Procure the required number of devices for implementation.
4. Establish the implementation time frame for the following sequence of activities:
    a. Preparation.
    b. Identify new device users.
    c. Familiarisation and training for new device users.
    d. Progressive implementation to build familiarity and experience.
    e. Data and feedback gathering.
    f. Ongoing support.
5. Finalise training and instruction references. These should be based on references used during Step 4 and include any identified improvements.
6. Develop a schedule for familiarisation and training for new device users. This training should be delivered by local “experts” who have become very familiar with the device during the Stage 4 assessment. This training and instruction may also include the manufacturer/distributor or external provider depending on the complexity of the device set up and configuration and any data gathering capability.
7. Finalise any ongoing feedback and data gathering mechanisms that will be used to track implementation progress. This should include:
    a. Direct feedback from devices users at any time.
    b. Standard feedback surveys (previously developed) for users and other stakeholders, such as supervisors, to complete at set periods within the implementation schedule.
    c. Quantified data where this is provided by the device.
8. Device protection:
    a. Prepare device protection measures based on the outcome of the Step 4 assessment. This should include any risk elimination or mitigation strategies related to the user of device protection measures/PPC.
9. Device cleaning:
    a. Confirm the device cleaning measures and methods to ensure that the users and those cleaning them are fully aware of the flow of the devices through the cleaning process and their responsibilities relative to disassembly and re-assembly of the device and where it is stored for next day use.
10. Device maintenance
    a. Confirm device maintenance measures, methods and frequency to ensure that preventative and reactive maintenance is conducted.
    b. Maintain a record of any device defects or requirements for maintenance and repair once the device has been implemented.
11. Finalise and the expected daily sequence of use for each device and employee who will wear it according to the outcomes of the Step 4 assessment (Section 3.4.1 point 13). This will vary for each job and should be used to help fast track the new participants’ uptake of the device.
12. Device storage:

a. Storage before use – specify where and how the device is stored after cleaning, where it is ready for use.
b. Storage after use – describe where (and how) the device should be delivered after use so it can be cleaned. For example, where is the device reassembled and who will do this.

9.3.5.2 Familiarisation & training

1. Provide familiarization and training sessions to new users and stakeholders (eg. supervisors).
2. Emphasize the knowledge of the physical demands of the targeted jobs, the assistive capacity of the device in reducing the physical demands of these jobs and the outcomes of the Stage 4 assessment that has led to the broad implementation of the device.
3. Train each new user how to prepare, don and fit the device to their body size, utilising those employees who have previously worn the device during the Step 4 evaluation.
    a. Choose or set the size to match the size of the new user.
    b. Prepare the device for fitment to the new user.
    c. Don the device and adjust for optimal fit. This should achieve a high level of comfort and not result in the exertion of localised pressure of any components on the new wearer's body through the expected range of movements.
    d. Confirm that an optimal fit is achievable and the settings to achieve that for each person.
    e. If it is not possible to achieve optimal fit of the device on a new user, determine why, inform the manufacturer/distributor and inform the employee that it will not be possible for them to commence use of the device.
    f. Provide each new user with a simple reference that describes how to prepare, don and fit the device.
    g. Provide each new user with repeated practice in preparing the device for fitment, donning it and then adjusting it for optimal fit until they can demonstrate competency in achieving a consistently high quality of fit of the device.
    h. The procedure for doffing the device should also be provided, demonstrated and practiced so each new user can consistently remove it in the same, safe manner.
4. Teach each new users how to adjust the device during non-operational activities:
    a. For some devices, such as back exoskeletons, the anchoring around the wearer's thighs will restrict their ability to walk unrestricted. This will require the device settings to be adjusted to de-activate the assistance function and allow other movements, such as walking to be undertaken. Once the new wearer and device are ready to perform the job, the device needs to be reactivated. For example, for back exoskeletons, the hip joint may need to be deactivated so it moves freely during walking.
5. Teach each new user how to adjust the assistance function(s) of the device:
    a. The assistance function(s) and settings should be clearly described.
    b. Before donning the device, instruct new users in the activation features of the device, what it does and how its settings are increased or decreased.
    c. Don the device with the assistance feature turned off, deactivated or set to its lowest level.
    d. Once the device has been fitted for optimal comfort and "anchoring" on the new wearers body, they should practice adjusting the control(s) to vary the setting levels up and down until they are competent.
    e. The initial assistance levels should be set so they are approximately 50 to 70% of the levels used by competent users. The assistance level should be progressively increased to match the new user's level of skill in using the exoskeleton.
    f. If the device uses active power, the new wearer should learn and practice how to shut it off quickly so it can be promptly disabled if required.
    g. Each new wearer's immediate co-workers and supervisors may also need to learn how to quickly deactivate the device.

h. Use of the work tools and equipment normally utilised by the participant should also be practiced before moving to the operational area, as much as practicable.
i. Contact the manufacturer/distributor if any issues of concern arise.

6. New users should be provided with any “tips and traps” references developed during the Step 4 assessment to help them fast track their learning about the safe and effective use of the device.

9.3.5.3 Initial implementation for new users

1. Commence the graduated use of the device in the targeted areas according to the schedule determined during the Step 4 assessment.
2. Ensure all new device users sign any consent forms for the collection, storage and use of data if this is required.
3. The following approach to the broad implementation of the exoskeleton device in the targeted operational area is recommended:
   a. The participant should be able to cease wearing the device at any time and for any reason, without consequence to them. The detail of this circumstance should be recorded, in confidence, to understand any factors that should be considered for the safe and functional use of the device by other participants.
   b. The participant should promptly report any hazards, risks, concerns or discomfort so the project co-ordinator can rectify the issue(s) or cease use of the device until any issues can be resolved.
   c. Utilise a graduated program for wearing the device to enable each participant to build up their level of use over a period of one to two weeks, and longer if required.
      i. The time scale for increasing wearing and use of the device should be based on the outcomes of the Step-4 assessment.
      ii. This graduated wearing of the device should also incorporate feedback from the participant and a slower rate of uptake should be used if required. A more rapid uptake of the device should only occur if there is a clear indication that it is safe to do so, and that the participant approves.
   d. The participant should reduce the level of assistance provided if they need to at any time and for any reason.
   e. A record of changes in the level of assistance engaged and the impact on the participant’s performance of the job should be kept on a daily basis until a pattern of use that is considered to be useful and safe by the participant is established.
   f. Records on consistent assistance settings for specific jobs should also be maintained.
4. Once the participants are confident in using the device and setting the assistance levels, they should be encouraged to utilise levels found to be appropriate within the Stage 4 evaluation process.
5. Once the participant has established a consistent pattern of use and activation settings for the device. They should perform the same jobs for a day without wearing the device. Their observations of the differences in their level of effort exerted to perform the same jobs should be recorded as one way of assisting them to identify any benefit and impact on their physical exertion when perform this work.
6. For any devices that collect data during use, configure the settings and the data to be collected, and how this will be downloaded, labelled, categorised, collated, analysed and reported as part of the device utilization. Ensure that this data is captured and catalogued on daily basis.

9.3.5.4 Ongoing review of progress

1. Ongoing implementation should be monitored via feedback from wearers and other stakeholders. If available, data generated from device use should also be used to monitor implementation progress and impact.
2. The same survey applied during initial testing should be recorded at the end of the first month (nominal time period) of use for each new wearer of the device.

3. Any feedback where improvements are identified should be responded to directly to assist the wearer. The manufacturer/distributor should also be contacted for any issues that requires their involvement or for which they should be made aware.

Step 5 – Exoskeleton implementation & consolidation outcome

1. Has the ongoing use of the device been successful?
   a. If yes, describe why.
   b. If no, describe why.
2. Has the manufacturer/distributor provided the level of supported indicated at the outset of the project?
   a. If yes, describe why.
   b. If no, describe why.
3. Should the device continued to be used in the current areas?
   a. If yes, summarise the reasons why and include any additional conditions or strategies to support their ongoing use.
   b. If no, describe why.
4. Should use of this device be extended to other areas.
   a. If yes, summarise the reasons why and any conditions or strategies needed to support implementation into these areas.
   b. If no, describe why.
5. Develop and implement further strategies based on the outcome of this review of broad scale implementation of the device.