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Standards for the safety of exoskeletons used by industrial workers performing manual handling activities: A contribution from the Robo-Mate project to their future development

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Abstract

Funded under the 7th Research Framework Programme of the European Commission, the goal of the Robo-Mate project is to develop an intelligent, easy-to-maneuver, and wearable body exoskeleton for manual handling work. Workers in the manufacturing industry are exposed to factors that increase their likelihood of developing Musculoskeletal Disorders (MSDs). The Robo-Mate industrial exoskeleton will be designed in accordance with best practice ergonomic principles to facilitate manual handling activities in multiple case study settings. An array of existing standards will be referenced in detail when designing the exoskeleton. As there is currently no standard that specifically targets the safety exoskeletons for industrial workers, it is intended to use Robo-Mate results to promote such development. To facilitate this process, a roadmap outlining tasks and responsibilities was created. It details who will oversee the process to promote and facilitate the further development of existing standards and ensure Robo-Mate results are targeted at suitable stakeholders. This will be achieved on three levels. In Level 1, the information will be directly communicated to standards developing bodies, specifically ISO, CEN and their members. In Level 2, assistance will be sought from organizations with interests in industrial robotics to add support to Robo-Mate when seeking to use the project's results to develop standards. Finally, the project details will be distributed to increase the awareness of the Robo-Mate project to the public, end-users, manufacturers, and distributers of industrial exoskeletons.

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Keywords: Robo-Mate; Standards; Exoskeleton; Musculoskeletal disorders; Safety

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1. Introduction

It has long been recognized that work and working environments are associated with workers' ill-health. Musculoskeletal disorders (MSDs), affecting muscles and joints, are one of the top causes of workplace absenteeism and early retirement due to workers' incapacity to carry out normal daily work tasks [1, 2]. The prevalence of the disorders is increasing with workers in all occupations worldwide being affected. Consequently, affected individuals, their employers, and the economy experience a significant financial burden [2-4]. Risk factors associated with the disorders include manual handling of loads, particularly with heavier larger or unwieldy loads, increased frequency or duration of manual handling activities, repetitive movements, and sustaining extreme or awkward postures such as bending, reaching, or twisting [1, 5, 6].

In an attempt to reduce workers' risk of developing MSDs, it is recommended that employers and designers implement a hierarchical duty of care when organizing work environments, and when designing tools and equipment with respect to the capacity and limitations of workers [7, 8]. To assist in manual handling activities, technological evolution has progressed from mechanized tools, to automated systems, to collaborative interactive robots, and of late, to wearable exoskeleton devices. On international and local levels, legislation, standards and codes of practices have been introduced in an attempt to minimize the presence of hazards in the workplace and reduce their levels of associated risk [9, 10]. However, the advancement in technology, such as the introduction of industrial robots, collaborative robots, and exoskeleton robots can occur at a rate with which the creators of these guidance requirements cannot match.

The EU funded Research and Development project, Robo-Mate, is bringing exoskeletons into the industrial workplace setting, and creating a device that augments the capacity of workers involved in manual handling activities. Using an industrial exoskeleton can reduce the burden on workers` health while maintaining or increasing production efficiency in all work environments where manual handling activities are required. The three-year Robo-Mate project started in September 2013 and is funded by the European Commission under the 7th Framework Programme for Research and Technological Development. Its consortium is comprised of twelve partners from seven countries, which includes end-users from automotive and dismantling industries, industrial robotics/ technology developers, a robotics integrator, and ergonomics research groups.

The work carried out in the Robo-Mate project will result in the accumulation of scientific and technological knowledge and expertise with respect to industrial exoskeleton development. In the research phase of the project, Robo-Mate participants will significantly expand their knowledge and expertise about manual handling activities in industrial settings, the limitations and capacity of the human body with respect to manual handling and movement kinetics and kinematics, and the design and compilation of an industrial exoskeleton. The details will be recorded in written reports, and data storage repositories. Additional knowledge and expertise will be gained in the development phase of the project. Design specialists will utilize the research data to initially construct functional exoskeleton prototypes and finally construct an industrial worker's lightweight, flexible, easy-to-wear, easy-to-maneuver, and intelligent exoskeleton in accordance with ergonomics principles.

One such way of disseminating and exploiting the projects' research results and new knowledge is through standardization. Standards are increasingly recognized as an important contributor to innovation. They provide minimum acceptable guidance for products and services i.e. ergonomically safe and reliable products that are compatible with the human form and its capabilities/limitations [11]. Products that are manufactured in compliance with applicable standards adhere to minimum quality and safety design criteria, are comprised of acceptable materials and components, and have been tested and evaluated. Additionally, the application of standards can assist in meeting legal requirements, can minimize costs associated with material selection and production, and facilitate interoperability within the European and global markets.

Standardization for the safety of industrial exoskeletons, a new design concept for workers involved in manual handling activities, is necessary to provide designers and users an agreed framework of criteria for its safe design, manufacture, and use. Having a product i.e. Robo-Mate exoskeleton, designed and manufactured in accordance with recognized international or European standards will help to improve the product's safety and reliability. This will increase the likelihood of product salability in a variety of industry settings in countries worldwide and will assist in enhancing users and employers confidence in the product.

This paper outlines the process used to establish the optimum method to disseminate and exploit the projects' research results and new knowledge for standards development.

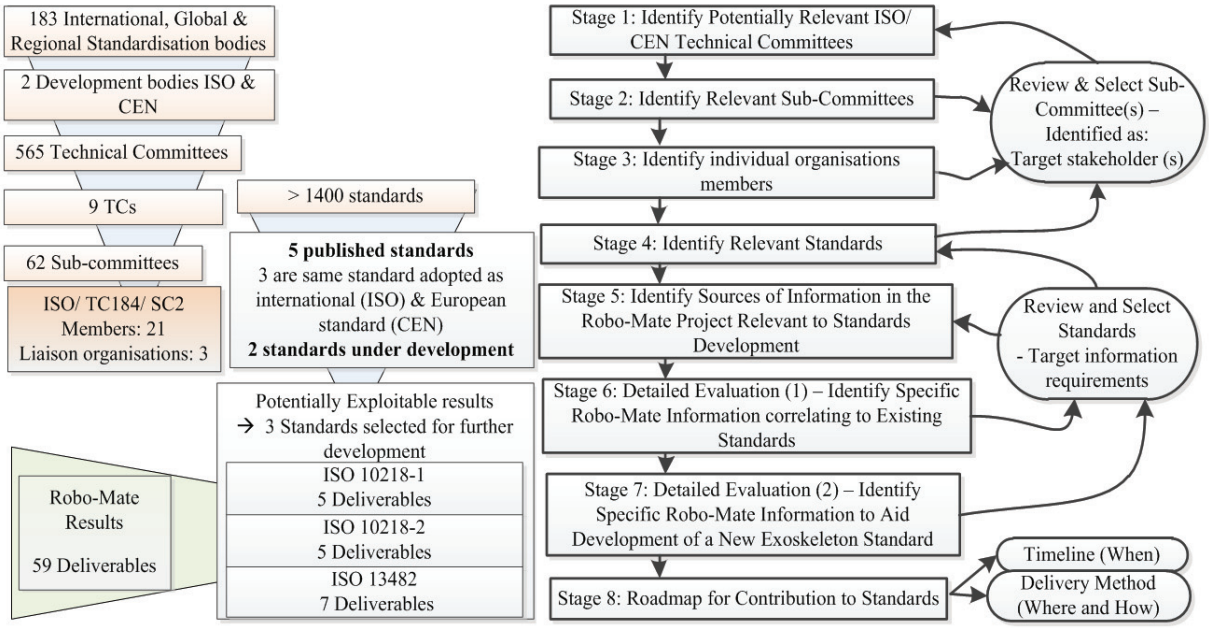

Fig. 1. Outline of the evaluation process used to optimize using Robo-Mate information to develop industrial exoskeleton standards.

2. Evaluation process

A cyclical inclusion/elimination evaluation process, graphically presented in Figure 1 was used to identify:

- Who to target?
- What standards, if any, are suitable for development using the projects' research results and new knowledge?
- What project information, research results, and new knowledge have potential to use for standardization?
- How, when and where the details will be transferred to the target population?

2.1. Who should be targeted to receive Robo-Mate information, research results, and new knowledge?

Selecting an audience to target is based on three factors; their involvement in developing standards, their ability to promote the development of standards, and their ability stimulate the demand for developing standards.

2.1.1. Standards developers

Standards organization bodies develop, coordinate, circulate, amend, reissue, and produce technical standards that are intended to address the needs of a wide base of affected adopters. The International Standardization Organization (ISO) develops and manages international standards and technical specifications that are voluntarily implemented across a wide range of sectors. CEN/CENELEC is responsible for the development and management of European standards. Their membership is comprised of the National Standardization Bodies (NSBs) in countries worldwide (ISO) and within Europe (CEN). Technical Committees (TC) and Sub-Committees (SC) in ISO and CEN are comprised of their NSB members and focus on developing standards within specific working areas.

Initially, 183 international, global, and regional standardization bodies were identified as potential targets to disseminate Robo-Mate results and information. Upon completion of the evaluation and elimination process, ISO TC 184/SC2, whose members are responsible for developing standards for Robots and Robotic Devices, was selected as the target standards organization body.

Ultimately, the decision to develop a specific industrial exoskeleton standard can only be made by the members of ISO/TC184/SC2 (or their possible successor). However, information provided by the Robo-Mate consortium can

demonstrate the advancements of exoskeleton technology and therefore prompt the development of appropriate standards. This may be achieved by developing a new industrial exoskeleton standard or amending currently published standards that correlate with the industrial exoskeleton. Benchmarking in this area will identify the highest standards of excellence for industrial assembly/dismantling or service-related processes and making the necessary improvements to reach or exceed those standards. Developing standards targeted at exoskeletons for use by industrial workers will assist in addressing the high prevalence of MSDs experienced by industrial workers.

2.1.2. Standards advocates

Upon carrying out a detailed internet search, and communicating with Robo-Mate partners and organizations involved in robotic research and development, an array of organizations with interests in promoting the advancement of robotics through research and development of industrial robotics were identified. Because of their membership composition, and their aims and objectives, four of these organizations were selected as potential standards advocate targets to disseminate Robo-Mate results and information.

The members of the European Factories of the Future Research Association (EFFRA), EURobotics, EUnited Robotics, and SPARC have networks of members from small, medium and large industrial enterprises, research organizations, universities, manufacturers of robots and robotic components, system integrators of robotics, and related stakeholders from across Europe. These organizations have the capacity to promote the Robo-Mate exoskeleton to a more targeted audience through their online resources, conferences and workshops. Additionally, the organizations can promote the requirement for policy and standards development that will prompt standards development organizations to develop specific targeted standards in response to advancements in research and technology.

2.1.3. Standards development stimulators

Increasing the awareness of the Robo-Mate project requires targeting individuals who will potentially benefit from the development of a safe reliable industrial exoskeleton. Examples of stakeholders who can stimulate the development of industrial exoskeleton standards include potential end users of the product, their employers, and safety personnel employed in manufacturing industries in which workers involved in manual handling activities are at risk of developing MSDs. Additionally, future manufacturers of industrial exoskeletons, when utilizing appropriate standards can facilitate the interoperability of collaborative and industrial robotic technology within European and global markets.

2.2. What standards should be targeted for further development?

Standards are best practice guidance documents that are voluntarily utilized and become mandatory when adopted as a legal requirement by regulators. Products that are manufactured in compliance with applicable standards adhere to minimum quality and safety design criteria, are comprised of acceptable materials and components, and have been tested and evaluated. The application of standards can assist in meeting legal requirements and can minimize costs associated with material selection and production. Many of the published standards will be referenced to guide designing the Robo-Mate exoskeleton.

While standards are published to guide the inherently safe design of service and personal care robots (ISO: 13482, ISO: 10218/1 and ISO: 10218/2), there is no specific standard applicable to industrial exoskeletons. Additionally, the harmonized standards published under the European Machinery Directive do not relate to a combined machine and wearable tool device.

Robo-Mate, with its industrial exoskeleton research and technology advancement, can contribute to benchmarking in the fields of robotic-enabled, flexible production and manufacturing processes. The consortium promotes the development of standards to govern the safety, reliability, and quality of industrial exoskeletons on an international and European level taking into account human factors issues. Initially, more than 1,400 published standards, under the control of potential target standards developers, were identified as possible target standards (Table 1). Upon completing an evaluation process to establish compatibility to industrial exoskeletons, the standards for service and personal care robots, ISO: 13482, ISO: 10218/1 and ISO: 10218/2 was deemed most appropriate for further development (Table 2).

Table 1. Standards developers (TCs) identified as potential target stakeholders; standards under their control.

Standards Technical Committees – evaluated as potential target stakeholders		Number of standards under their control – evaluated as potential target standards for further development
ISO/TC 184	Automation systems and integration	753
ISO/TC 159	Ergonomics	119
ISO/TC 94	Personal safety -- Protective clothing and equipment	115
ISO/TC 173	Assistive products for persons with disability	74
ISO/TC 168	Prosthetics and orthotics	21
ISO/TC 199	Safety of machinery	44
ISO/TC 39	Machine tools	165
CEN/TC 122	Ergonomics	107
CEN/TC 310	Advanced manufacturing technologies	11

Table 2. Target standards considered for further development – after evaluation process.

Published Standard (under control of ISO/TC184/SC2)	Consideration for selecting to further develop
ISO 13482 – 2014: Robots and robotic devices - Safety requirements for personal care robots	Specifies requirements & guidelines for the safe design, protective measures, and information for personal care robots. This is the only published standard in which the term exoskeleton is provided to refer to a physical assistant robot
ISO 10218 /1-2011 Robots and robotic devices - Safety requirements for Industrial Robots, Part 1- Robots	Specifies the requirements and guidelines for the inherent safe design, protective measures, and information for use of industrial robots
ISO 10218/2-2011 Robots And Robotic Devices- Safety Requirements for Industrial Robots: Part 2 Robot Systems & Integration	Specifies requirements for the integration of industrial robots and industrial robot system as defined in ISO 10218 - 1

2.3. What Robo-Mate information, research results, and new knowledge should be targeted to aid standards development?

The Robo-Mate 'Description of Work' (DoW) document outlines and describes the project's goals and objectives for 13 Work Packages (WP), 57 tasks, and 11 milestones. Upon completion, 59 deliverables will be generated, 30 classified as 'reports', 23 classified as 'other,' and nine classified as 'prototype'. While each deliverable is essential in guiding the research and development of the industrial exoskeleton, they have variable relevance is assisting in the development of an industrial standard exoskeleton. During the evaluation process, the goals and objectives for each project output were comparably evaluated to the contents of potential target standards with respect to further development to incorporate industrial exoskeletons. Based on the content and structure of the target standards, seven of the report deliverables are identified as generating the main source of usable information that has potential to further develop the standards. In addition to providing terms and definitions that are specific for industrial exoskeletons, Robo-Mate will provide information such as details and guidelines outlining:

- Hazard management including hazard identification and subsequent risk reduction strategies,
- Safety requirements and protective measures for the manufacture, normal use, failure events and emergency events of the industrial exoskeleton,
- Verification and validation of the industrial exoskeletons' functional design and safety design,
- Maintenance and inspection requirements of the industrial exoskeleton,
- User and service manuals, and labeling and marking guidelines.

2.3.1. Safety policy

The development of a safety policy to assist in developing future standardization commenced early in the concept design phase and develops as the project progresses.

Using existing and relevant standards to provide benchmark guidelines, a Robo-Mate Safety Expert panel developed a hazard database detailing potential hazards throughout the lifecycle of the Robo-Mate industrial exoskeleton. Each hazard is evaluated and risk mitigation and/or risk reduction strategies identified. Designers were provided with physiological, biomechanical and ergonomic data to guide the design of the industrial exoskeleton to ensure a functional and safe industrial exoskeleton capable of undertaking desired tasks in targeted work environments while accommodating the capabilities and limitations of potential users. Systems were developed to enable testing, verification, and validation of the design concepts of the Robo-Mate prototypes, the end product and their sub-components.

'Normal' use scenarios, and 'emergency situation' scenarios, taking into consideration expected and unexpected use, were considered to guide the hazard identification and risk reduction process with a view of designing an intrinsically safe Robo-Mate exoskeleton. The standard policy will develop as knowledge and experience evolve in the Robo-Mate project until the design concept is finalized, the components and technology are selected, and the safety and health issues evaluated.

2.4. How can Robo-Mate information, research results, and new knowledge be distributed to target stakeholders?

Dissemination of Robo-Mate information, research results, and new knowledge to the target stakeholders is achievable through a variety of outlets. Stroyan and Brown [12] carried out a review of EU Framework Programme (FP) projects, specifically FP6 and FP7. They evaluated projects and their role in using results to contribute to standardization development and standards utilization and established that:

- Up to a third of projects use standards as an input to their research, (as has Robo-Mate),
- Up to one in eight projects involve or lead directly to proposals for new or revised standards, and
- Up to one in twelve projects contribute directly to the development of new or revised standards.

When proposing a new or revised standard, the results were shared, presented or submitted to appropriate people and organizations via scientific articles and other publications (e.g. project reports, newsletters), project websites, conferences, workshops, direct mailings, media campaigns, and the project team's involvement in relevant standardization committees and working groups.

3. Robo-Mate Roadmap

To facilitate dissemination of the selected Robo-Mate project's information, research results, and new knowledge to the desired stakeholders in a timely manner required the appointment of consortium member facilitators and a standards development team to oversee and manage the process. The team coordinated their activities to:

- Develop a safety policy for future standardization development,
- Write a White Paper document: *A review of standards and considerations for developing safety standards for exoskeletons used by industrial workers*,
- Publish Robo-Mate Newsletters - 4th issue published in April 2015,
- Write papers targeted at specialist conferences, and
- Write papers targeted at specialist journal publications.

A tabular format of the Roadmap with an example of its contents is presented in Table 3. The Robo-Mate details will be disseminated to all target stakeholders once the Robo-Mate facilitators upon completing their review of submitted deliverable documents and reports. This may involve the delivery of the same, or similar, information packs to multiples of stakeholders at the same time using a variety of distribution methods.

Table 3. Standards considered for further development.

Timeline (When)	Partner (Who)	Task (what and where)	Target Stakeholder	Delivery process (How)
18/19 June 2015	Level 1 Robo-Mate representative	Participate in ISO TC184/SC2 meeting (June 2015), with a view to informing the stakeholders about the project, advantages of using exoskeleton, outlining possible Robo-Mate results that may assist in further developing standards; Robo-Mate White paper on contributions to standards development presented.	ISO TC184/SC2 – NSB members	Initial: Seek authorization to attend the meetings, access resources; plan and prepare for meeting.

3.1. Disseminating details to standards developers

Only (NSB) members of a technical committee can participate in the standards development process. The Robo-Mate consortium can indirectly participate in cases where a partner's NSB is a member in the committee, and their NSB authorizes permission to attend and participate. A Robo-Mate member has subsequently received permission from ISO/TC184/SC2 to attend their meeting scheduled for 18th - 19th June 2015 at Berufsgenossenschaft Holz und Metall in Stuttgart. He will present an outline of the Robo-Mate project, demonstrate the potential risk reduction benefits of an industrial exoskeleton, and summarize the potential information, research results, and new knowledge that the Robo-Mate project can deliver to assist in developing an appropriate industrial exoskeleton standard.

In addition to a presentation, and question and answer session at the meeting, Robo-Mate details will be distributed in the form of an information pack containing copies of the Robo-Mate newsletters, a copy of the Robo-Mate White Paper and other Robo-Mate documents.

It is important to note that regardless of the quality or quantity of detail presented to the committee, the final decision to develop an existing standard (or develop a new separate standard) will only be made by the committee members. In the event that they deem it unnecessary, disseminating Robo-Mate details to the remaining stakeholders becomes more important.

3.2. Disseminating details to standards advocates

The robotics promotion organizations (EFFRA, EURobotics, EUnited Robotics, and SPARC) have added Robo-Mate to their email database, thereby allowing Robo-Mate distribute details (newsletters, media releases, White Paper etc.) directly to 1,000's of robotics research and development organizations. Additionally, Robo-Mate receives information from the members and also has the option to attend the organizations' future conferences and workshop events.

3.3. Disseminating details to standards development stimulators

Disseminating Robo-Mate details to those who have potential to stimulate the requirement for developing an exoskeleton standard will primarily be through media releases and conference/journal publications. Consortium members have, and as the project progresses, are continuing to write a number of ergonomics and robotic conference and journal papers that were selected based on the background of the attendees and readers. To date, a number of media releases have been broadcast in the countries of the project partners through local and regional radio, newspaper and television, and on partner's websites and publications.

Robo-Mate will host and will attend workshops targeted at potential industry users, manufacturers, and robotics researchers. The first Robo-Mate industrial exoskeleton workshop is scheduled for Friday, 12 June 2015 in Fraunhofer IAO, Stuttgart, Germany.

4. Conclusions

The Robo-Mate project proposes to research and develop an industrial exoskeleton, which when used by workers carrying out manual handling activities will reduce their risk of developing MSDs. In addition to promoting its distribution to an international market and increasing confidence in the product, which can motivate the desire for its

introduction into the workplace, the application of appropriate standards can help to ensure the safe and reliable design, manufacture and use of the exoskeleton.

To date, there is no standard that applies specifically to industrial exoskeletons. To promote the development of such a standard, Robo-Mate has carried out a detailed evaluation of the standardization process to identify target stakeholders who can assist in appropriate standardization development. Likewise, compatible standards were identified as targets for potential further development and incorporate industrial exoskeletons. A review of Robo-Mate's deliverables highlighted which information, research results, and new knowledge could contribute to the development process. Finally, consortium members were appointed to oversee the dissemination process using a variety of methods to enable the distribution of the Robo-Mate details to the target stakeholders.

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