ViVA – Virtual Vehicle Assembler

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Project within FFI-Sustainable Production Technology

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1 Summary

The challenge in the proposed research project is to develop a demonstrator of a production engineering digital human modelling (DHM) tool considering human diversity, to be used for design, optimisation, visualisation, and verification of vehicle assembly workstations.
The overall aim is to develop a supportive production engineering tool that:
1) automatically can predict human behaviour considering dynamic effects and analyse human work in manual work stations from a musculoskeletal viewpoint.
2) automatically can optimise workstations where humans are supported with exoskeletons or collaborative robots.
3) consider human diversity in terms of appearance, shape, clothes, and safety equipment used during work.
4) easily can be understood, used and manipulated as well as adapted to recent developments within immersive VR and digital twin solutions.

The project is divided into a number of work packages that will lead the project towards the final objectives. From each work package, new knowledge and sub-solutions will be developed and implemented in a demonstrator. Throughout the project, the demonstrator will be tested and evaluated by industrial and academic partners. Cases from collaborating companies will be used to verify outcomes and provide feedback for further developments. A final demonstrator tool, combining the knowledge and solutions gained from the project, will be developed and allow for easier further adaptation and implementation in companies.

WP 1: Project coordination and demonstrator development (Dan Lämkull, Volvo Cars)
WP 2: Dynamics and muscle models (Niclas Delfs, FCC)
WP 3: Human-robot collaboration and exoskeleton support (Anna Brolin, University of Skövde)
WP 4: Manikin appearance and personas descriptions (Erik Brolin, University of Skövde)
WP 5: VR and digital twin (Peter Mårdberg, FCC)
WP 6: Industry cases (Fredrik Ore, Scania CV)

The project has developed methods, algorithms and a software tool that enables productivity increase in manufacturing engineering. Test cases indicate that developed functions significantly speed up the production realization development process. In some of the cases the time reduction was as much as 25%. In this way, the project contributes towards a vehicle industry in Sweden that continues to be competitive.

In WP 2 a novelty muscle model has been developed with:
- an improved user interface
- dynamics reformulation – more efficient / reaction forces in joints
- the usage of a new solver for large indefinite systems
- a muscle editor
- a joint settings dialogue

In WP 3 a CAD model of an exoskeleton, and LUA script based solution of how to simulate external forces, and the biomechanical effects, of using exoskeleton, using IPS IMMA have been developed. Furthermore a solution of how to optimize ergonomics and productivity has been developed.

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- new anthropometric data in IPS-IMMA is prepared for implementation
- method for handling skewed anthropometric data has been developed
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- tool for for including agility and strength data (data driven personas) have been initiated
- wardrobe has been developed with safety items (gloves, glasses, helmets and shoes)
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In WP 5 the main work has been focused to finetune the VR functionalities and to possibility to control the IMMA manikin with VR controllers, HMD and optional trackers on the body, the support

for the Xsens motion capture system and VR functionalities testing as well as to test the application on industrial use cases.

In WP 6 all participating companies contributed with industrial cases.
All industrial partners (CEVT, NEVS, Scania and Volvo Cars) have contributed with eight industrial cases where all the functionality in the project have been demonstrated. At regular project meetings (total 8) intermediate project results have been presented. At these meetings all industrial partners have presented how the developments from academy partners are integrated and used in the company cases. Furthermore analyses to try to find efficiency figures related to research developments have been conducted. In general some of the research results have led to a decrease in needed time to perform ergonomics analyses and production improvements. In some cases the reduction of needed time has been reduced with approx. 25%.

2 Background

Both European, e.g. Horizon 2020, and Swedish research agendas, e.g. Vinnova, FFI 2017, describe a clear and substantial need for smart production preparation, digitalization, and ICTbased Design for X technologies to shorten the time for product and production development, and to increase output quality of these processes, while meeting sustainability objectives. Efficient digitalization and ICT-based tools are needed for design, modelling, simulation, optimisation, visualisation, and forecasting of production processes, resources, systems, and factories during their life cycle. Digital factory models need to be created before the actual physical factory is realized to easily and fast explore different design options, evaluate their performance, virtually commission automation system, and verify the manual systems, thus reducing critical time to production and supporting superior production performance and sustainability. Furthermore, digital factory models need to be maintained throughout the lifetime of the production to guarantee an effective and efficient connection, and consistency with the actual physical factory. In addition, reconfiguration options need to be tested in the virtual factory with the use of modelling and simulation tools and then, after validation, the changes are implemented in the real factory in a short time. The evolution of the real factory will be reflected and stored into the virtual models of the factory.

The European and Swedish research agendas, e.g. Vinnova Production 2030, also focus on people in production and the physical and cognitive aspects of people in production health, demographic changes, and wellbeing, in order to meet social sustainability objectives. These describe a need to improve our ability to monitor health and to prevent, detect, treat, and manage disorders and diseases, realised by supporting the development of efficient and effective tools, and intervention methods. This in order to create better health for all people and keep elderly people active and independent for longer time. The assembly worker is one of the most important resources within the vehicle production process. The current vehicle production process consists of plenty of manual work. Most likely also future electrical and autonomous driven vehicles will be assembled by humans, although with a likely increase of collaborative robot support. Sweden has a world leading tradition within human centred design and ergonomics, and Vinnova’s Sustainable Production document (Vinnova, 2015) points out that this position should be kept and strengthened, without ignoring productivity and competiveness.

Digital human modelling (DHM) technology is positioned in the union of these two important and challenges, *Design for X Technologies* for supporting production preparation, focused on *People in Production*. By simulation and visualisation of ergonomics, DHM tools enable proactive consideration of user diversity and biomechanical impact, and risks due to work tempo, workstation, and work task design. There exist a number of commercial DHM tools on the market that support a proactive approach towards human centric design of products and workplaces. The Swedish industry uses these tools to some extent, but the usage should expand. The current DHM tools are now challenged by the introduction of the Swedish *IPS IMMA* DHM tool developed by researchers from Fraunhofer-Chalmers Centre, University of Skövde and Chalmers, in close collaboration with Swedish industry. In the SSF funded *IMMA* project (2009-2013, ProViking/PV09.13) the research groups jointly developed a tool for automatic collision free path planning of digital manikins (human models). In the FFI Vinnova project *CROMM - Creation of Muscle Manikin* (2013-2016, Dnr 2012-04584) the groups continued their research and development on dynamics and muscle modelling of human models, and then manikin motion simulation and evaluation in point cloud scanned factories and layout planning

in the Vinnova SIO (Strategiska innovationsområden) production project *3D-SILVER* (2015-2017, Produktion2030, 2015-01451). In the FFI Vinnova project *Virtual Verification of Human Robot Collaboration* (2016-2018, Dnr 2015-03719) research and development actions are performed to enable simulation of human models performing collaborative work with industrial robots. The *MOSIM* project within ITEA 3 (Dnr: 2018-02227) frames the group together with European and Canadian partners to perform research to find approaches and algorithms for simulating natural human motions, time setting of motions, and concurrent ergonomics and productivity balancing.
The CROMM and Virtual Verification of Human Robot Collaboration projects have resulted in a stable basic DHM software based on the IMMA results, as well as promising results at concept levels for modelling muscles in the shoulders as well as the possibility to, in one software, handle both human and robots for virtual verification of human-robot collaboration workplaces. Before the algorithms and simulation approaches reach the expected levels of functionality and usability for industrial use, the muscle models algorithms need to be further developed and simplified, and safety aspects in human-robot collaboration workstations need to be further investigated. A new and complementary type of human-robot collaboration approach has the opportunity to assist humans in future production, the exoskeleton, where the assisting robot is attached to the worker. The exoskeleton approach was not considered in the previous human-robot collaboration project. Furthermore, visualisation and manipulation of the digital human modelling tool need to be adopted to the ongoing digitalization trends where VR and controls are used to enhance the users' immersion in the virtual world, and to facilitate manipulation of manikins and objects. Finally, the current DHM tools, including IPS IMMA, have limited functionality to model more rare human body shapes, and typically only offer one appearance of each gender of the human models, typically looking like a middle-aged fit male and female.

3 Objective

Since the proposed project is based on earlier FFI projects (CROMM and Virtual Verification of Human Robot Collaboration), results possible to implement can, within a very short time, be delivered to product development projects to make the demonstrator functionalities available in commercial versions of IPS IMMA. The digital human modelling demonstrator base created within this project will form an excellent base for further activities. The proposed project will result in algorithms for a highly automated software that can be used in digital production preparation of vehicle assembly production and allow industry partners to:
- Predict, visualise, and optimise human wellbeing and overall system performance in vehicle assembly. The product and workstation design can be verified by industry to ensure that the design and its production are efficient and are adapted to existing and future worker demographics related challenges.
- Increase the efficiency of the product and production preparation process and advance the flexibility to make changes. This by using a DHM tool for simulation and visualisation early in the design process, using a tool that has the functionality to consider production efficiency in parallel with ergonomics of workers assembling parts on vehicles, or performing similar work tasks.
- Increase the efficiency of production by making workstations and products adapted to a diversity of operators. It is well documented that ergonomically designed products and workplaces result in healthy and motivated users and workers, experiencing better comfort and causing fewer work-related musculoskeletal disorders. Additionally, operators working in ergonomically designed workplaces are producing more products (higher productivity) and products with fewer errors (higher quality) (Vink et al., 2006; Falck et al., 2010). Hence, good ergonomics corresponds with good economics.
- Decrease the environmental impact of the production preparation process and of the production, and improve the product and production development process. Using a human simulation and visualisation tool in the design process enables a reduction of number of physical prototypes, and that less workstation redesigns and rebuilds are required. Having humans producing products of high quality being right-first-time leads to less waste and reduced number of rejects, hence less extra parts and energy used in production.
- The proposed project will further strengthen Swedish research through building competence and global publicity, supporting the involved academic partners and industries position as one of the leading actors in the area of applied ergonomics and

applied digital human modelling.

4 Project realization

Project aim

The challenge in the proposed research project is to develop a demonstrator of a production engineering digital human modelling (DHM) tool considering human diversity, to be used for design, optimisation, visualisation, and verification of vehicle assembly workstations.
The overall aim is to develop a supportive production engineering tool that:
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The project is divided into a number of work packages that will lead the project towards the final objectives. From each work package, new knowledge and sub-solutions will be developed and implemented in a demonstrator. Throughout the project, the demonstrator will be tested and evaluated by industrial and academic partners. Cases from collaborating companies will be used to verify outcomes and provide feedback for further developments. A final demonstrator tool, combining the knowledge and solutions gained from the project, will be developed and allow for easier further adaptation and implementation in companies.

Work packages

WP 1: Project coordination and demonstrator development (Dan Lämkull, Volvo Cars)
Within this work package a detailed project plan including scheduled milestones will be delivered and continuously followed up and updated. Several internal and a few external meetings and workshops will be arranged. Furthermore, progress and project reports will be written. The demonstrator is central in the project and knowledge gained in other work packages are implemented in the demonstrator. The demonstrator is the major result from this work package. The demonstrator will be used for facilitating the dialogue between researchers and industrial partners and will secure that the outcome of the research project is what is desired and gradually becomes integrated in the cooperating companies' organisations.

WP 2: Dynamics and muscle models (Niclas Delfs, FCC)
In the current version of IPS IMMA, biomechanics is calculated and evaluated from analysis of the manikin's skeleton model by assessing joint characteristics, where simulations are based on a quasi-static approach. In the research project CROMM, basic muscle models and dynamics functionality were developed. Currently embryos of muscles for the hand, arm and shoulder are available. The objective is to increase the technology readiness level (TRL) of dynamics and muscle modelling. This by developing the functionality further, based on methods developed in CROMM, and finally implement results in the IPS IMMA tool. Examples of research questions to be answered are: 1) to what extent, and in which of the industry cases, is dynamic modelling important in vehicle assembly?, and 2) to what extent, and in which of the industry cases, is worker muscle strength the limiting parameter? The result from the work package is a dynamic *manikin equipped with muscles, enabling musculoskeletal assessments.*

WP 3: Human-robot collaboration and exoskeleton support (Anna Brolin, University of Skövde)
In the current commercial version of IPS IMMA no functionality to simulate human-robot collaboration is available. A research version is available that has the basic functionality, e.g. to include and manipulate a robot and a human in the same simulation scene. There is no functionality available to equip manikins with exoskeleton support. The objective is to increase the technology readiness level of the human-robot collaboration functionality, especially by developing and evaluating ergonomics and productivity assessment methods. Functions for

adding virtual exoskeleton models will be added and exoskeletons' effect on workers will be evaluated both in the virtual and physical world. Examples of research questions to be answered are: 1) what tasks are commonly performed by who (human versus robot) in a collaborative workstation where both human and robot as well as ergonomics and productivity is considered?, and 2) what are the effects of wearing a exoskeleton in terms of productivity and human health? The result from this work package is a digital human modelling tool that can be used for automatic optimisation of workstations where workers are supported by either collaborative robots or exoskeletons.

WP 4: Manikin appearance and personas descriptions (Erik Brolin, University of Skövde)
In the current version of IPS IMMA one manikin per gender, with a given appearance and clothing, carrying no safety protection, is provided. In reality, all humans are unique and characteristics and appearance differs between individuals. Previous research has shown that visualisation and manikin appearance affects interpretation and decision making. Therefore there is a need for human like manikins that represent the diversity within the population. Furthermore, safety protection equipment is often mandatory in manufacturing. The manufacturing equipment may affect the human behaviour and the possibility to perform a task. Therefore, the manikin needs to be equipped with clothes and safety protection equipment as in real life. The objective of this work package is to equip the manikins with highly functional, flexible and representative skin and appearance models. To reach the goal, methods from computer gaming and movie making will be introduced in the digital human modelling field. Furthermore, scanning technology will be used to gather body contours that should be matched to the manikin model. Examples of research questions to be answered are: 1) what are the effects of personas and improved appearance related to trust of digital human simulation results?, and 2) what effects has safety equipment on manikins’ behaviour? The resulting personas, considering anthropometric difference for length, strength, flexibility, and body contours, will offer natural appearances that can represent workforce diversity. The feature will also offer a wardrobe for the manikin, including clothes as well as additional items such as safety protection equipment, and the function to attach persona descriptions to manikins.

WP 5: VR and digital twin (Peter Mårdberg, FCC)
The current version of IPS has initial functionality for immersive VR and digital twin solutions. Embryo functions have been developed within the CROMM and Virtual Verification of Human Robot Collaboration projects. The objective is to use the VR technology to improve manipulation of the manikins and to control the task to be done by the manikin, as well as to improve the visualisation and understanding of simulation results. Furthermore, the objective is to develop the tool to enable the manikin to become a digital twin of the real human worker. Examples of research questions to be answered are: 1) will VR and hand controls to manipulate the manikin increase usability?, and 2) will the facilitated connection between digital and physical world with the digital twin solution increase the usefulness and trust of digital human modelling? The result from the work package is a manikin that is easy to manipulate and that has a predicted trustworthy behaviour. Another result is a manikin that is connected in real time with a worker in the physical world.

WP 6: Industry cases (Fredrik Ore, Scania CV)
During the development of the current version of IPS IMMA, a participative development process was utilised. This means that end users from industry describe their needs in the form of representative and/or challenging industrial cases. This participative process supported usability and meant that functions being developed were relevant and efficient. The objective of this work package is to continue to utilise this successful approach to define, perform, and evaluate industry based use cases. This approach will advance the demonstrator tool’s functionality and *usability in an iterative manner. The industry partners will use the IPS IMMA demonstrator to* solve industry problems and give feedback on improvements. This work package will secure that a relevant and efficient demonstrator is developed, and encourage the industry partners to be active in the project activities as well as to disseminate project findings and demonstrator developments within their respective company organisation.

Relevance to the program

In FFI’s sustainable strategic roadmap, six main focus areas are mentioned: 1) *New products*, 2) *Competitiveness*, 3) *Environment*, 4) *Quality*, 5) *Lead time*, and 6) *Flexibility*. The proposed project focuses on research and development within the area of digital human modelling in the

context of digitalisation of product and production development processes, manual or semimanual assembly and human wellbeing. Digital human modelling research and development is nconsidered not to explicitly contribute to the focus areas *New products* and *Flexibility*. Still, the research findings in the project will be implemented in coming versions of IPS IMMA (*New software products*), offering *Flexibility* in the sense that the tool can be applied to assist engineers in decision making in a large number of different tasks and domains. To some extent the project contributes the focus area *Environment* by reducing the needs for building or modifying physical prototypes for verification of design proposals (as discussed in the section *Expected results and use of the project result*). The proposed project is however claimed to predominantly contribute to the three remaining focus areas: *Lead time*, *Quality*, and *Competiveness*. These three focus areas highlight the need of using virtual tools to meet objectives. Within the competitiveness area, virtual tools for ergonomic simulation and work place design is even explicitly mentioned. The scope of the proposed project is to create a user friendly DHM tool for vehicle production preparation, which is a topic that perfectly match with the SMART production preparation area defined within the FFI program. The final demonstrator will reduce the lead time, both related to time to market and time to volume, and support engineers to faster and more successfully identify high quality solutions in the integrated product and production development process, in turn providing enhanced competitiveness.
The lead time, quality, and competiveness focus areas also consider the human aspects, mentioning good work environment, consideration of demographic characteristics and healthy workers at all levels all the time as important areas for research. In the proposed project, vehicle assembly workers' wellbeing is central, with concurrent consideration of overall system performance. The project also considers human diversity and demographic characteristics by *enabling the creation and use of personas in the DHM tool.*

Deliveries to FFI-goals

The project has developed methods, algorithms and a software tool that enables productivity increase in manufacturing engineering. Test cases indicate that developed functions significantly speed up the production realization development process. In some of the cases the time reduction was as much as 25%. In this way, the project contributes towards a vehicle industry in Sweden that continues to be competitive.

In WP 2 a novelty muscle model has been developed with:
- an improved user interface
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In WP 6 all participating companies contributed with industrial cases.
All industrial partners (CEVT, NEVS, Scania and Volvo Cars) have contributed with eight industrial cases where all the functionality in the project have been demonstrated. At regular project meetings (total 8) intermediate project results have been presented. At these meetings all industrial partners have presented how the developments from academy partners are integrated and used in the company cases. Furthermore analyses to try to find efficiency figures related to research developments have been conducted. In general some of the research results have led to a decrease in needed time to perform ergonomics analyses and production improvements. In some cases the reduction of needed time has been reduced with approx. 25%.

5 Results and deliverables

The main technical results and deliverables of the project are:
- a toolset for calculate muscle activities and joint forces
- new method for simulating biomechanical effects of using exoskeletons
- a solution for prediction of strength and torque values based on age, sex and weight of manikin has been delveloped
- a tool for for including agility and strength data (data driven personas) have been initiated and a wardrobe has been developed with safety items (gloves, glasses, helmets and shoes)
- possibility to control the IMMA manikin with VR controllers, HMD and optional trackers on the body
- new anthropometric data in IPS-IMMA is prepared for implementation.

6 Dissemination and publications

6.1 Knowledge- and disseminations

How have the project results been disseminated or used?	Markera med X	Comments
Increase the knowledge within the area	X	-
Passed on to other advanced technical development projects	X	-

The industry partners and the research group will jointly and continuously execute dissemination and exploitation activities throughout the project, with an equal balance of academic and industry activities.

Industry impact
At the end of the project, a simulation, optimisation, and visualisation demonstrator software for digital human modelling and workstation verification will have:
- functionality for advanced modelling of human body shapes, appearances and creation of personas.
- functionality to simulate forces in muscle enabling musculoskeletal assessments.
- functionality for assessment of human-robot collaboration from an ergonomics and productivity point of view.
- functionality for automatic optimisation of workstations where workers are supported by either collaborative robots or exoskeletons or both.
- full VR support and an efficient way of interaction.

Several potential workstations from project partners will be used as industry based use cases for developing the demonstrator. Within the project, at least two industry cases at each partner will be carried out. The project will also use the ASSAR Industrial Innovation Arena in Skövde for physical assessments and experiments regarding exoskeletons' ability to reduce workers work load. The research project will also analyse whether the exoskeletons are limiting the workers' work envelopes. Effectiveness of the demonstrator software in visualising appearances and human-robot collaborations will be compared to the current methods used in industry.

Training sessions for how to operate the demonstrator software will be offered regularly to project partners during the project, with invitations also to external partners. Training sessions will be arranged every sixth month. Industry partners participating in the project are working on a global market and have manufacturing plants all over the world. Hence, the actions and outcomes from the project will spread within each participating partner's organisation. In the end of the project the demonstrator software is to be presented on a concern level at each partner. Open seminars and webinars will be organised for people from the academy and industry. A series of seminars with about 7 meetings per year will be organised along the project. The final demonstrator software will be displayed at internal and external conferences both in Sweden and abroad. The demonstrator will get an extra visibility 2020 when Chalmers, FCC, and University of Skövde host the Digital Human Modelling Symposium, held in Sweden for the first time.
The ASSAR Industrial Innovation Arena in Skövde will also be utilised. ASSAR is an integrated innovation environment in Skövde. The initiators of this venture are University of Skövde, Gothia Innovation AB, Volvo Group, Volvo Car Corporation, and Industrial Development Center West Sweden AB.

6.2 Publications

Hanson, L., Högberg, D., Brolin, E., Billing, E., Iriondo Pascual, A. & Lamb, M. (2022). Current Trends in Research and Application of Digital Human Modeling. In: Nancy L. Black; W. Patrick Neumann; Ian Noy (Ed.), Proceedings of the 21st Congress of the International Ergonomics Association (IEA 2021): Volume V: Methods & Approaches. Paper presented at 21st Congress of the International Ergonomics Association (IEA 2021), 13-18 June (pp. 358-366). Cham: Springer

Hanson, L., Högberg, D., Iriondo Pascual, A., Brolin, A., Brolin, E. & Lebram, M. (2022). Integrating Physical Load Exposure Calculations and Recommendations in Digitalized Ergonomics Assessment Processes. In: Amos H. C. Ng; Anna Syberfeldt; Dan Högberg; Magnus Holm (Ed.), SPS2022: Proceedings of the 10th Swedish Production Symposium. Paper presented at 10th Swedish Production Symposium (SPS2022), Skövde, April 26–29 2022 (pp. 233-239). Amsterdam; Berlin; Washington, DC: IOS Press

Iriondo Pascual, A., Högberg, D., Syberfeldt, A., Brolin, E., Perez Luque, E., Hanson, L. & Lämkull, D. (2022). Multi-objective Optimization of Ergonomics and Productivity by Using an Optimization Framework. In: Nancy L. Black; W. Patrick Neumann; Ian Noy (Ed.), Proceedings of the 21st Congress of the International Ergonomics Association (IEA 2021): Volume V: Methods & Approaches. Paper presented at 21st Congress of the International Ergonomics Association (IEA 2021), 13-18 June, 2021 (pp. 374-378). Cham: Springer

Garcia Rivera, F., Lamb, M., Högberg, D. & Brolin, A. (2022). The Schematization of XR Technologies in the Context of Collaborative Design. In: Amos H. C. Ng; Anna Syberfeldt; Dan Högberg; Magnus Holm (Ed.), SPS2022: Proceedings of the 10th Swedish Production Symposium. Paper presented at 10th Swedish Production Symposium (SPS2022), Skövde, April 26–29 2022 (pp. 520-529). Amsterdam; Berlin; Washington, DC: IOS Press

Garcia Rivera, F., Brolin, A., Perez Luque, E. & Högberg, D. (2021). A Framework to Model the Use of Exoskeletons in DHM Tools. In: Julia L. Wright; Daniel Barber; Sofia Scataglini; Sudhakar L. Rajulu (Ed.), Advances in Simulation and Digital Human Modeling: Proceedings of the AHFE 2021 Virtual Conferences on Human Factors and Simulation, and Digital Human Modeling and Applied Optimization, July 25-29, 2021, USA. Paper presented at AHFE International Conference on Human Factors and Simulation and the AHFE International Conference on Digital Human Modeling and Applied Optimization, 2021, Virtual, Online, 25 July 2021 - 29 July 2021, USA (pp. 312-319). Cham: Springer

Perez Luque, E., Högberg, D., Iriondo Pascual, A., Lämkull, D. & Garcia Rivera, F. (2020). Motion Behavior and Range of Motion when Using Exoskeletons in Manual Assembly Tasks. In: Kristina Säfsten; Fredrik Elgh (Ed.), SPS2020: Proceedings of the Swedish Production Symposium, October 7–8, 2020. Paper presented at 9th Swedish Production Symposium (SPS2020), 7-8 October 2020, Jönköping, Sweden (pp. 217-228). Amsterdam: IOS Press

Brolin, E., Högberg, D. & Hanson, L. (2020). Skewed Boundary Confidence Ellipses for Anthropometric Data. In: Lars Hanson, Dan Högberg, Erik Brolin (Ed.), DHM2020: Proceedings of the 6th International Digital Human Modeling Symposium, August 31 – September 2, 2020. Paper presented at 6th International Digital Human Modeling Symposium, August 31 – September 2, 2020, Skövde, Sweden (pp. 18-27). Amsterdam: IOS Press

Reinhard, R., Mårdberg, P., García Rivera, F., Forsberg, T., Berce, A., Mingji, F. & Högberg, D. (2020). The Use and Usage of Virtual Reality Technologies in Planning and Implementing New Workstations. In: Lars Hanson; Dan Högberg; Erik Brolin (Ed.), DHM2020: Proceedings of the 6th International Digital Human Modeling Symposium, August 31 – September 2, 2020. Paper presented at Proceedings of the 6th International Digital Human Modeling Symposium, August 31 – September 2, 2020, Skövde, Sweden (pp. 388-397). Amsterdam: IOS Press

Garcia Rivera, F., Brolin, E., Syberfeldt, A., Högberg, D., Iriondo Pascual, A. & Perez Luque, E. (2020). Using Virtual Reality and Smart Textiles to Assess the Design of Workstations. In: Kristina Säfsten, Fredrik Elgh (Ed.), SPS2020: Proceedings of the Swedish Production Symposium, October 7–8, 2020. Paper presented at 9th Swedish Production Symposium (SPS2020), October 7–8, 2020 (pp. 145-154). Amsterdam: IOS Press, 13

Perez Luque, E. (2019). Evaluation of the Use of Exoskeletons in the Range of Motion of Workers. (Student paper). Högskolan i Skövde.

Lämkull, D & Zdrodowski, M. (2020). The Need for Faster and More Consistent Digital Human Modeling Software Tools. In: Lars Hanson; Dan Högberg; Erik Brolin (Ed.), DHM2020: Proceedings of the 6th International Digital Human Modeling Symposium, August 31 – September 2, 2020.

7 Conclusions and future research

To automatically predict human behaviours considering dynamic effects and analyse human work in manual work stations from a musculoskeletal viewpoint will continue to be developed. It is a very complex task to solve and an automatic generation of human motions by just picking on a part to move is by far from an existing function. Before a function like that is existing we will continue to use motion capture and/or manual jogging of the digital humans' joints. However, this research project has shown some progress and these do really justify to continue developing and improving the algorithms developed in this research project in other coming research projects. There are also discussions in the project group about continuing the successful collaboration in other research projects funded by VINNOVA.

8 Participating parties and contact persons

Volvo Cars:	Dan Lämkull
Scania:	Fredrik Ore
CEVT:	Anton Berce
Chalmers:	Lars Hanson
Högskolam i Skövde:	Dan Högberg
Fraunhofer Chalmers:	Johan Carlson
NEVS:	Left the project before formal end