POLITECNICO DI TORINO

Master's Degree in Automotive Engineering

Master's Degree Thesis

Virtual Simulation and its application in industry: an overview of current technologies and future trends

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Abstract

The thesis explores the use of virtual simulation tools particularly Digital Human Modeling (DHM) — in different fields. It gives special attention to how DHM can be used in production planning and also the pre-emption of MusculoSkeletal Disorders (MSDs); discusses the evolution and spheres of Motion Capturing and VR techniques. The paper talks about the rising significance of virtual simulation in industry, lists different software tools and their features. It presents an ergonomic evaluation case study using Jack software; a case on Motion Capture implementation at Ford; a VR implementation case at General Motor. These cases underscore possibilities for improving workplace design, task analysis towards promoting employee well-being and system effectiveness.

Keywords

Digital Human Modeling (DHM), Ergonomics, Virtual Simulation, Production Planning, MusculoSkeletal Disorders (MSDs), Software Tools, Jack, Ergonomic Evaluation, Motion Capture, Virtual Reality.

Chapter 1

1. Introduction of the virtual simulation in ergonomic field.

Ergonomics is derived from the Greek words 'ergon' (work) and 'nos' (laws)- a field of scientific study that endeavors to understand the relationship between humans and other components of a system. It's also considered an applied field of study that aims to ensure design theory, principles, data, and methods contribute to the improvement of human health and wellness, while also maintaining a primary goal of improving the system while preserving the health of the human. At its core, ergonomics promotes the idea that the job should correspond to the person and not expect the person to correspond to the job — also in regards to the design of workstations, tools, and tasks (both physical and psychological). Through this approach that takes into account safety and productivity in addition to comfort, ergonomics attempts to prevent injury or illnesses that are caused by musculoskeletal issues or physical or psychological exposure to hazards in the workplace.

At first, the concern of ergonomics was centered on the industrial field, and it was associated with improving the efficiency and joy of workers. Ergonomics now includes all human endeavors that involve the utilization of artifacts. The practitioners (primarily ergonomists who include many applied psychologists) have attempted to find such integrated approaches that take into account physical, mental, social, and environmental aspects all together. As a result, we have four primary fields in ergonomics today: Physical, cognitive, neurological, and social or organizational [1].

Virtual simulation tests related to ergonomics during the product design phase help to identify and fix possible problems in the product development and manufacturing— cost and risk reduction. In the same way, if designers do multiple designs, tests, and optimizations on computer they will have fewer physical prototypes made and tested (efficiency in design and manufacturing). As we discussed before, physical ergonomics mainly study preventing fatigues and injuries during the work, cognitive ergonomics however, focus on analyzing the mental process including user-friendly interaction between human and systems. Neuroergonomics use neurophysiological tools to study costumer preference on computer interference design and their visual attention on the product. The domain of Social or Organizational Ergonomics revolves around improving the performance and interplay of work systems — with the involvement of multilateral scientific collaboration to mold the social and structural dimensions in organizational environment. We will mainly discuss physical ergonomics in this thesis because the main ergonomics applications in industry field are most related to injuries such as MusculoSkeletal disorders.

1.1 The increasing role of virtual simulation in production planning

Virtual simulation has contributed a lot in production planning mainly due to the following reasons:

1) Cost and Risk Reduction: Because after the product development is completed and the production line is built, any modification will cost a lot of manpower and material resources, so virtual simulation avoids this risk in advance, which will save the company a lot of money.
2) Design and Manufacturing Efficiency: Designers can carry out multiple designs, tests, and optimizations on the computer without having to produce many physical prototypes— which would have been done for testing purposes— thus enhancing efficiency in both design and manufacturing.
3) Customization and Personalization: Virtual simulation technology can carry out virtual simulations based on user demands and product features which will in turn enable companies to realize more customized product design plus personalized production: a service provision tailor-made to fit your peculiar demand specifications, even when it comes to specific color preferences.
4) Innovation and Upgrading: The virtual simulation technology created for enterprises make them be able to think out of the box, creating more space to

imagine the future, continuously driving upgrades and new innovations into products, hence increasing the level of competitiveness for enterprises.

Industrial production also benefits a lot from ergonomic simulation. It helps the designers create a safe and comfortable workspace that meets the physical and psychological requirements of workers by simulating work situations and studying them. Through workflow simulation, ergonomics is able to identify motions that are unnecessary — which could be reduced — as well as steps that can be optimized for better efficiency. Working environment simulation helps in predicting safety risks and health issues: this ensures improvements are made before production starts hence reducing accidents which lead to occupational diseases. Ergonomic simulation takes into account console heights and tool layout considerations within workspace design— while ensuring human dimensions fit the workstation, thus making it comfortable for people to work there. The digital twin technology, which is a virtual representation of a physical object or system that mirrors the real-time behavior and performance of the physical entity, facilitates full oversight and fine-tuning of manufacturing activity from end-to-end. To wrap it up, the significance of virtual simulation in production planning is steadily rising. It paves new ways for future evolution of the manufacturing sphere by enhancing effectiveness, reducing risk, encouraging personalization and fostering innovation.

1.2 Ergonomic virtual simulation in industry field

Industrial production benefits from ergonomic simulation as it enables designers to establish work places that are safer and more efficient. It also helps in addressing the physiological and psychological needs of the workers by simulating work environments and tasks. Through the simulation of workflows, ergonomics is able to bring out motions that are not necessary by identifying and eliminating them— hence optimizing steps towards efficiency. The simulation work place helps to predict safety risks plus potential health issues thus preventive measures can be improved before operationalization of production lines which significantly reduces accidents as well as occupational diseases. Workspace design is a key consideration in ergonomic simulation including console height and tool layout with a focus on fitting human dimensions because such an environment tends to provide comfortable working conditions: enhancing operator satisfaction, indirectly promoting quality of output. From machines to people, we study and improve their functioning while working. By including Digital Human Models (DHM) in this virtual environment, it can be used as a tool for managing ergonomic problems and also estimating numerical values of ergonomics indexes scores [2]. Optimizing the performances of systems and humans, even as they function together in actual operating environments. When Digital Human Models (DHM) are incorporated into this virtual setup, it becomes feasible to address ergonomic concerns and compute numerical values for ergonomics indexes with an engineering approach [2][3][4].

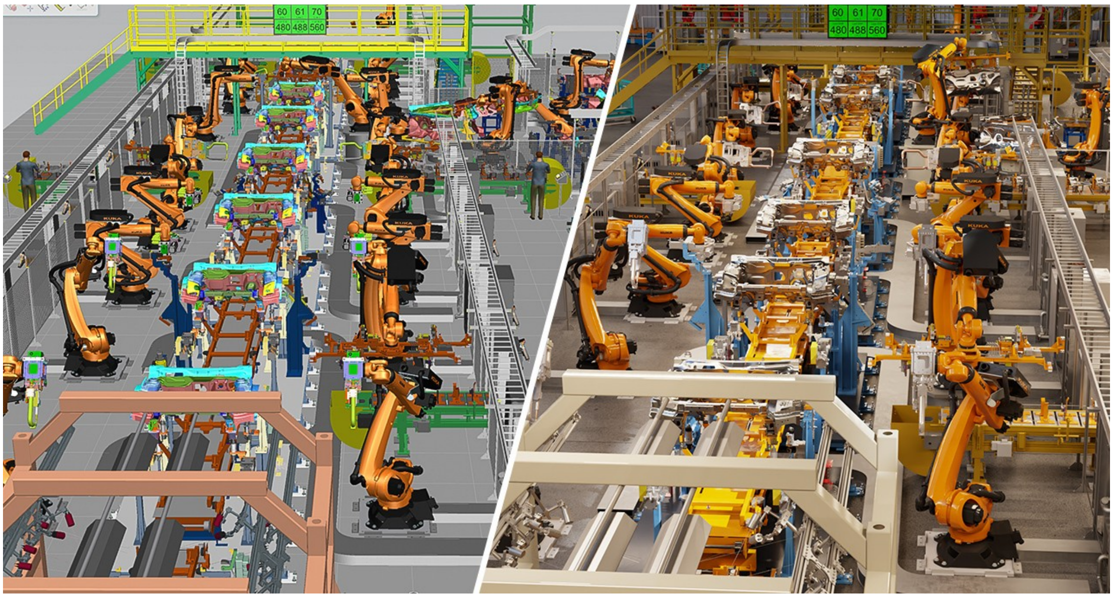


Figure 1 digital twins of a factory.

1.3 An introduction to DHM

Digital Human Models (DHM) are not real people but virtual representations depicted in three dimensions. These manikins help designers see their design before they even make a physical prototype— allowing preproduction assessment of designs to take place. Jack, Ramsis, and Safework are common DHM software that work similarly to Computer-Aided Design (CAD) programs— making it easy for users to import their 3D CAD models into a virtual workspace without any difficulty. Within this virtual space, designers can select mannequins of different sizes, proportions, and shapes: all combined for an analysis on the design at hand as though the work were taking place in a real location with actual people present.

The use of DHM programs allows various design considerations to be evaluated. Consider a scenario where an automotive company uses DHM: to determine if the seat adjustability is feasible for all users within easy reach while also providing access to all necessary controls. DHM does not only benefit the end user but is also greatly useful in examining manufacturability and maintenance — ensuring accessibility to components for assembly or repair. Moreover, DHM facilitates ergonomics consideration in the optimization of workplace design and safety-related issues. All these details are best dealt with digitally during the design stage — leading to high-quality designs that can be easily obtained without incurring high costs due to wastage on inappropriate physical prototypes.

The use of digital human modeling can lead to reduced production costs and the effective implementation of delivery schedules— ensuring safety, which then boosts profitability for the business. Anthropometric models deal only with physical measurements related to size and shape. Biomechanical models delve into the dynamics of physical behavior: how parts move or interact under different loads or motions. Production models are an aggregate of workflow simulations from discrete event simulation techniques (which simulate the primary system while considering human action) and work time prediction from data.

1.4 The different softwares available on the market in this field

There are three main commercialized DHM packages used for ergonomic design of products [5]:

• Jack is an advanced Digital Human Modeling (DHM) software included in the Tecnomatix suite, a creation of Siemens PLM Software. It’s engineered for enhancing ergonomics in product design and streamlining industrial tasks. More detailed introduce of software Jack will be in the following chapter.

Figure 2, software Jack

• SafeWork, initially developed by a Canadian ergonomic consulting company, now purchased by Dassault Système and renamed as Human Builder in CATIA. The primary purpose of this tool is to support ergonomic analysis and human factors engineering. Professionals use it to simulate task-related human motion that helps assess physical ergonomics for products and workplaces.

Here are some key features of SafeWork:

Ergonomic Analysis: It allows visualization of individuals in action — focusing on clearance and reach, two important aspects in ergonomics.

Human Motion Simulation: SafeWork was initially designed for static postures but it has capabilities for human motion simulation; this feature under task-oriented dynamic conditions significantly increases the realism of ergonomics evaluation that can be achieved with the program.

The development of the software has taken into account a wide range of users; this includes experts as well as those who are not knowledgeable in the field to use SafeWork. SafeWork is part of a tool family that includes Jack and Ramsis, and its use greatly impacts the development process. This contributes to ergonomics design which should ensure worker safety and comfort— one of the primary components for such software.

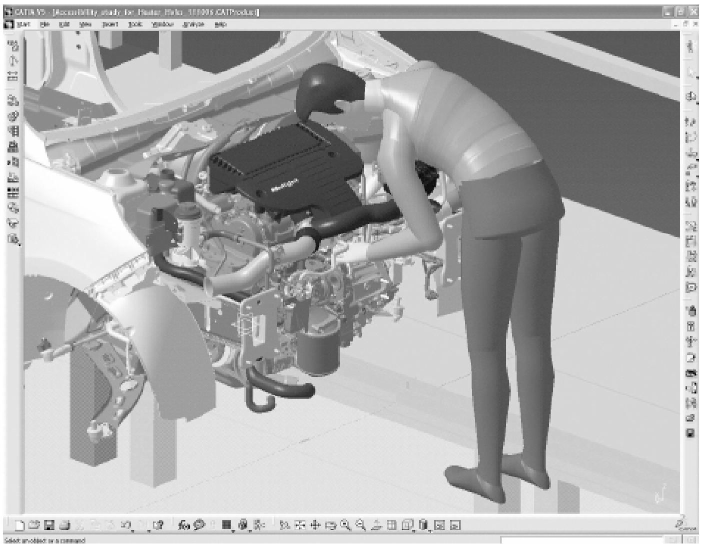


Figure 3, software safework.

• RAMSIS is a leading 3D CAD manikin and ergonomics simulation software developed by Human Solutions GmbH. It is extensively used in the automotive sector for carrying out ergonomic analysis of vehicle interiors, which helps guarantee a high level of product maturity and keep low the demand for physical prototypes during early developmental stages.

For example, some key features of RAMSIS are:

Realistic Simulation: With the help of the largest anthropometric database in the world, it can create any 3D target group distinguished by its size, gender, population and age-related features in an individual manner.

Role-based Posture Calculation: Different occupants are assigned specific roles that come with typical posture and movement models — a feature RAMSIS computes automatically based on the vehicle interior.

Integration of Field Studies: Field studies are integrated in the software which provides information on the movements of vehicles plus what elements work inside a vehicle.

Animation and Movement: With an emphasis on animation and movement, RAMSIS presents numerous animation and simulation functions that make it possible to depict manikin movements during process simulation.

Ergonomic Analysis: When considering an ergonomic analysis, RAMSIS offers tools that include optimal reachability, direct and indirect vision analysis, room and space requirement calculations, as well as ingress/egress analyses.

RAMSIS is available as standalone software for Windows or fully integrated into CAD platforms like Catia V5 and Siemens NX. It has wide applications across different sectors such as automotive and defense, apart from just aircraft, where it plays a role in guaranteeing the products' safety, comfortability, and appropriateness to the intended users.

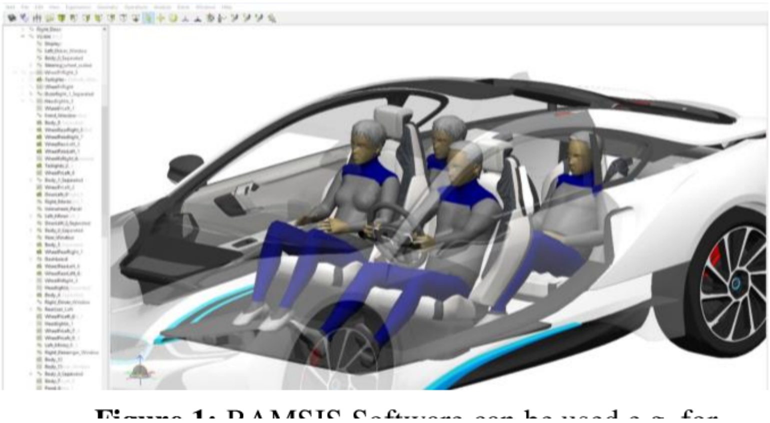


Figure 4, software Ramsis.

In addition,

• CATIA-DELMIA Human Builder: Formerly known as Safework, this tool is integrated into the CATIA suite and offers comprehensive ergonomic evaluation features for product design and manufacturing processes.

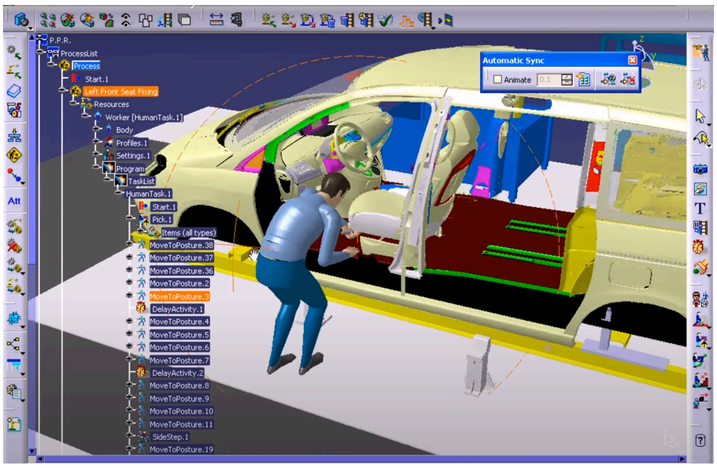


Figure 5, software CATIA-DELMIA Human Builder

• The SAMMIE system is a computer based Digital Human Modelling (DHM) tool. Developed originally at Nottingham University in the UK it is one of the longest standing and respected DHM tools. Its capabilities make it an invaluable tool to designers, ergonomists and design teams working on products that are used by people.

Here are some key aspects of SAMMIE:

Human-Centric Design: SAMMIE is used by designers, ergonomists and design groups to produce products that are user-friendly and ergonomic — meaning they are designed considering the ease of use by people.

Versatile Application: The program can be applied to a wide range of environmental contexts. This includes public spaces, offices, homes, vehicle interiors, control panels, safety assessments...

Early Development Assessment: It enables early intervention during the design phase so as to ensure that the design suits the intended user population before finalizing the most critical features.

Anthropometric Variation: SAMMIE can modify the sizes of human models to show various nationalities and genders— thus portraying a varied user population.

Real-World Problem Solving: By integrating ergonomics with design and Digital Human Modelling (DHM) technology, SAMMIE aids in practical evaluation and real-world problem solving.

SAMMIE CAD Ltd., the developer of SAMMIE, provides consultancy services on use of DHM tool for enhancing product, workplace, and service design after adoption.

Figure 6, software SAMMIE

• IMMA, which stands for Intelligently Moving Manikin, is an additional DHM package used for ergonomic analysis. It belongs to the IPS IMMA family of manikins and it is a user-friendly tool that aids the user in creating families that accommodates the intended population performing assembly operations.

Here are some notable features of IMMA:

Innovation in Path-Planning: In the IMMA, the smart path-finding feature guarantees dependability through innovative path-planning methods. This aims to ensure the repeatability of simulations and that the manikins adopt postures in an ergonomically plausible manner.

Comprehensive Evaluation of Ergonomics: Through this software, a comprehensive ergonomic risk assessment is conducted— which then guides designers with recommendations after determining the level of identified risk.

One manikin family simulates multiple human operators in IMMA which means anthropometric diversity can be dealt with through one simulation.

Compatibility with Standards: This feature enables organizations to establish ergonomics proactively and take into account the requirements of health and safety standards such as ISO and CEN at the stage of integration.

IMMA is an acronym standing for Intra MEmory Multivariate Analysis which is a technique that finds significant application in the risk evaluation of Musculoskeletal Disorders (MSDs). The primary goal of any design activity is to arrive at the best solution that ensures the well-being of the end-users, and this interestingly positions IMMA as a tool of interest to industries. The organizations are keen on keeping a stable and motivated workforce which can be achieved through the use of IMMA to shun work related ailments by adoption of good ergonomic practices, fostering creativity within their workspace— where all employees feel part and parcel of the team that is appreciated for their effort and contribution towards attainment of organizational goals.

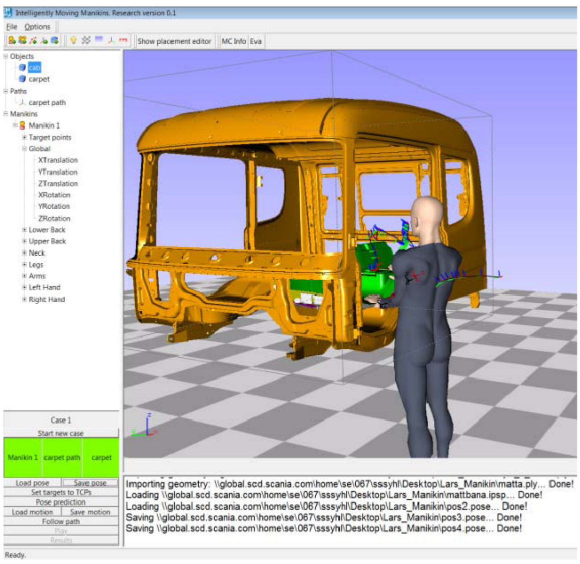


Figure 7, software IMMA

•AnyBody Modeling System: A system that allows one to develop and assess the interactions of systems related to muscle, bone and joint. This program is an effective means in modeling the human body working with its physical environment; highly known for use in musculoskeletal modelings.Here are some key features of the AnyBody Modeling System:

Advanced Simulations: It is able to run advanced simulations, through which each muscle force and joint contact forces plus moments can be determined individually.

Musculoskeletal Modeling: A necessary part of the software is an extensive model repository (AnyBody Managed Model Repository) that includes many body parts and actions.

Inverse Dynamics Analysis: Users can perform inverse dynamics analysis through the software to gain insight into internal biomechanical processes that occur during motion.

The AnyBody Modeling System is more than just a tool for those interested in biomechanics, ergonomics, sports science and rehabilitation engineering. It is able to simulate human motion and posture mechanics under various situations which makes it a versatile assistant to achieve the optimization of product design.

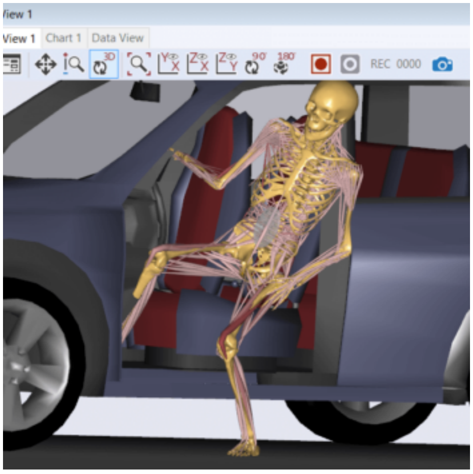


Figure 8, software AnyBody Modeling System

1.5 Functions comparison between Jack, Imma and Ramsis.

A comparison between the three software, Jack, Imma and Ramsis can be seen:

Functions:	Jack	Imma	Ramsis
Simulate family	-	x	x
Simulate family simultaneously	-	x	-
Define anthropometrical key-variables	x	x	x
Manikin positioned in most ergonomic posture by software	x	x	x
Manikin avoides collision with itself	x	x	x
Manikin avoides collision with objects	x	x	x
Script method available to instruct manikin to walk from A to B	x	-	-
Script method available to instruct manikin to get an object	x	x	x
Manikin moves an object from predefined start and end position	x	x	-
Predefined grips available in software	x	x	x
Manikin decides fitting grips by itself	x	-	x
handle flexible materials	-	x	-
Control what the manikin is looking at	x	x	x
Define force on manikin	x	-	-
perform an ergonomic evaluation	x	-	x
add other standard for evaluation	x	x	-
Evaluation result presented in software	x	x	x
Possibility to export evaluation result	x	-	x

[6]

Chapter 2

2. Basic introduction to software Jack

In the domain of DHM software, Jack is considered a pioneer in the field of ergonomics and human factors that are combined to facilitate the design of products and improve the efficiency of workplaces. When Siemens acquired Tecnomatix, Jack found his new residence under the umbrella of the Tecnomatix brand as a human simulation toolkit that provides feedback in real time and is user-friendly for various applications. It lacks the need for professional expertise in ergonomics. This facilitates the optimization of workplace designs to the point of specific line-ofassembly tasks: a design that is focused on user ease of use, this feature was developed with the intention of making it easy for non-expert developers to utilize it during the early stages of product development. As small companies or consultants lack the necessary resources or knowledge to utilize anthropometric data at later stages, utilizing Jack will have a significant impact on the way design is conducted, this is because it is not your typical product, but rather a simulation tool that revolves around how design is carried out. The utilization of the Digital Human Modeling (DHM) enables individuals to place lifelike digital humans (varying in size and the accuracy of their biomechanics) into virtual environments. This attribute provides both view and reach space, as well as human power and torque information, but it is primarily composed of animations and images that are directly related to the subject, and they are all depicted with supplementary information that is intended to clarify the subject.

Functional efficiency issues are revealed by analyzing the ergonomic conditions of workers through TAT (task analysis tools). In this research, we utilize a diverse array of TATs, rather than a simple random sample. NIOSH's lifting methodology, OWAS, RULA... are just a few of the many. All of the results will be displayed in a web browser. Easy access to everyone involved, so that they can discuss the results without having to hassle. Jack, an instrument that calculates and simulates the ergonomics of a workplace, is not simply any ordinary device. It exhibits the capacity of users to place virtual humans that are bio-mechanically accurate and of any imaginable size in virtual environments. Additionally, users can evaluate these digital creatures and then assess their effectiveness. Jack is full of basic tools that assess the functionality of the Digital Human Modeling (DHM). The zone of view, the reach zone, the human-powered force and torque... all of these are demonstrated through images and animations for a more convenient explanation. Jack doesn't just stop there, he also creates definitions, manipulations, animations and analyses of virtual humans; as a result, many problems related to physiological efficiency are revealed following the analysis. With TAT (task analysis tools) being employed in this research as mentioned previously. The investigation employs various TATs, including the NIOSH lifting procedure OWAS RULA, these are then easily accessible via a web browser for the purpose of reporting the results, which in turn allows for a discussion of the findings that are presented in the report. The impact of Jack is felt across the entire industry, and creates new standards. The research and development associated with Jack has contributed to the development of Hanimator, among other standards-based approaches to inverse-kinematics, which have, as a result, had a significant impact on the human motion systems utilized by animation companies like Industrial Light and Magic.

In a nutshell, Jack brings human capabilities together with the requirements of modern production design and places where people work. When organizations make this an ongoing practice within their policies— it is an indication that it works very effectively towards not only improving the welfare of the workers but also enhancing performance in the company.

2.1 Introduction of tools in Jack

Jack is an ergonomic simulation and evaluation product, which enables the users to position bio-mechanically accurate digital humans of various sizes in virtual environments. With tasks assigned and performance analyzed, Jack equips users with a variety of ergonomic tools used for the assessment of Digital Human Modeling (DHM) such as view zone or reach zone. Human force and torque are also measured while animations and images vividly illustrate the results found. Jack can bring forth many physiological efficiency issues revealed by TAT after analysis on worker's ergonomics with task analysis tools. In this work, a rich collection of TATs will be used— NIOSH lifting analysis, OWAS, RULA... just to name a few. The findings are made available through reports generated within the web browser which ensures ease in accessibility for discussions thereafter.

The NIOSH lifting analysis tool can help determine the symmetrical and asymmetrical lifting tasks and give appropriate scientific suggestions. It also provides an approximate measure of the physical stress and damage which is scientifically based on NIOSH lift equation, relative to a manual lifting task. This includes Recommended Weight Limit (RWL) and Lifting Index (LI) that shows relative estimate of level physical stress — where higher LI values represent greater risk for low back pain — if applicable, Cumulative Lifting Index (CLI) that shows collective demands from a job. When workload becomes excessive, some results will change color to yellow or red if too high.

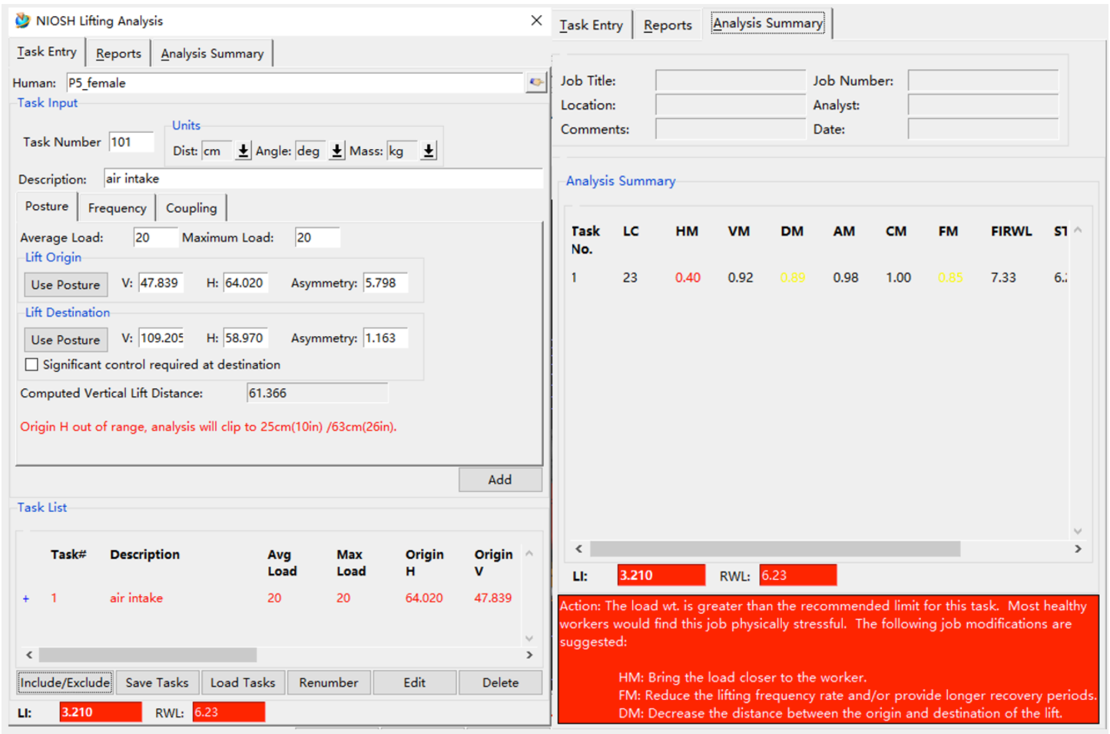


Figure 12, NIOSH Analysis tool in Jack.

The OWAS acronym refers to the Ovako Working Posture Assessment System. It is a simple but efficient way of identifying poor postures while working. Rather than just identifying the problem, OWAS also assesses the severity and various components contributing to musculoskeletal risk— such as load requirements and specific aspects of posture like back or arm position based on substantial research developed over two decades since OWAS was introduced. The findings from an OWAS analysis could lead towards designing manual tasks with minimal postural discomfort risks, which calls for uni-caf workers' effective operation.

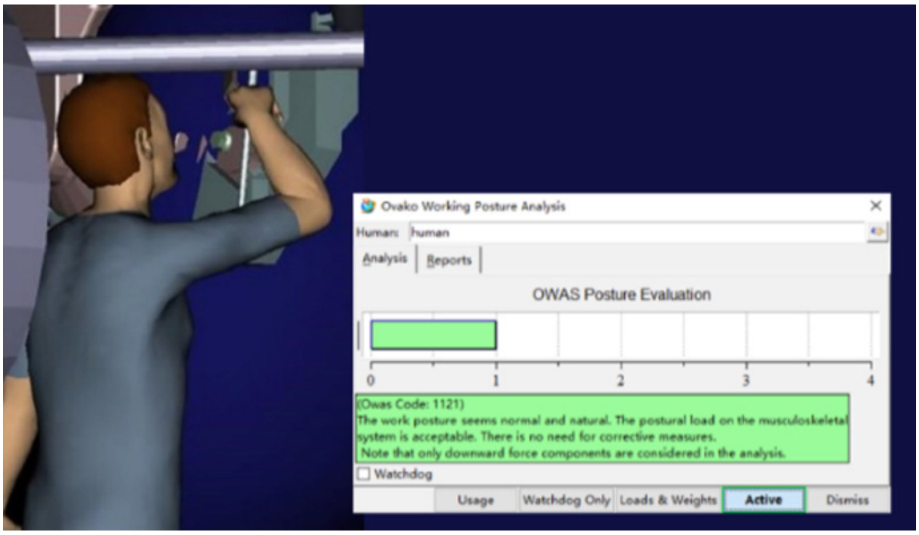


Figure 10，OWAS analysis tool in Jack.

RULA is a useful tool to evaluate the exposure of workers to the risk of upper limb disorders. This assessment tool is widely used for studying musculoskeletal disorders (MSD). The survey methodology adopted by RULA goes deep into work-related upper limb disorders [7] investigation aimed at human posture— as per Jack's definition. RULA introduces a scoring mechanism where the rationality of muscle use and force is judged and presented through a pop-up dialogue box with task-specific action levels highlighted. An analysis summary window follows suit, depicted with varying colors to denote different risk levels associated with posture— allowing easy inference on whether muscle use and loads go beyond specified limits [7].

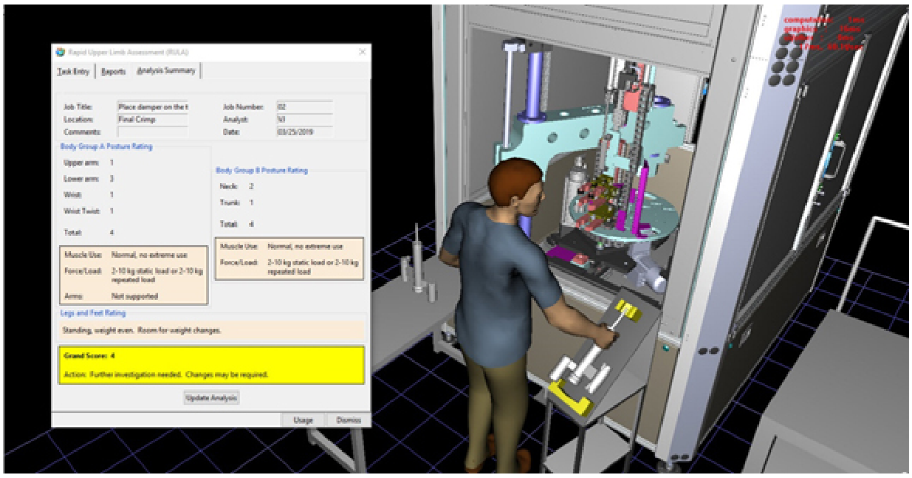


Figure 11, RULA analysis tool in Jack.

In addition, Jack has metabolic energy expenditure tool which helps predict metabolic energy requirements of a specific task [8]. This is done to determine if job tasks expose staff members to high levels of fatigue and injury risk, as well as identifying whether tasks present optimal opportunities for reducing overall energy expenditure needs. But most significantly, this analysis should be able to identify what particular aspects have the greatest impact on these tasks and be able to forecast what effect changes (based on those findings) would guide job design. The results will show an estimated 'energy cost' for each task measured in kilocalories [8]—calculated based on factors such as force, distance, frequency, posture, etc., against recommended limits. Color coding highlights instances where task limitations are exceeded (along with proposed solutions aimed at reducing injury risks).

Over the past two decades, the description of the human form in Jack has undergone a radical transformation. Initially represented as a simple and abstract collection of tetrahedrons (refer to Figure 12), it is now portrayed as a highly sophisticated and realistic model that reflects human biometric details along with anatomical features. This transition finds its roots in the most recent anthropometric data that allows for the generation of human figures based on as many as 26 different body measurements — including but not limited to overall height, seated stature and buttock-knee length. The virtual mannequin features an advanced kinematic chain which imitates the human skeletal structure; joints are designed with natural constraints while surface geometry reproduces actual human contours. Detailed models of spinal and shoulder mechanisms drive motion through reverse kinematics ensuring lifelike movement— all based on real-world physiology data. Users are able to pose these figures in any position that they want from an extensive library. They can also establish restrictions on the movement of the figures based on particular situations. For example, they can make sure that a pilot's hand stays on the control stick. Jack even allows users to create virtual worlds using its CAD tools and wide variety of objects available— ranging from basic shapes all the way up to intricate furniture or other items you might find in real life settings.

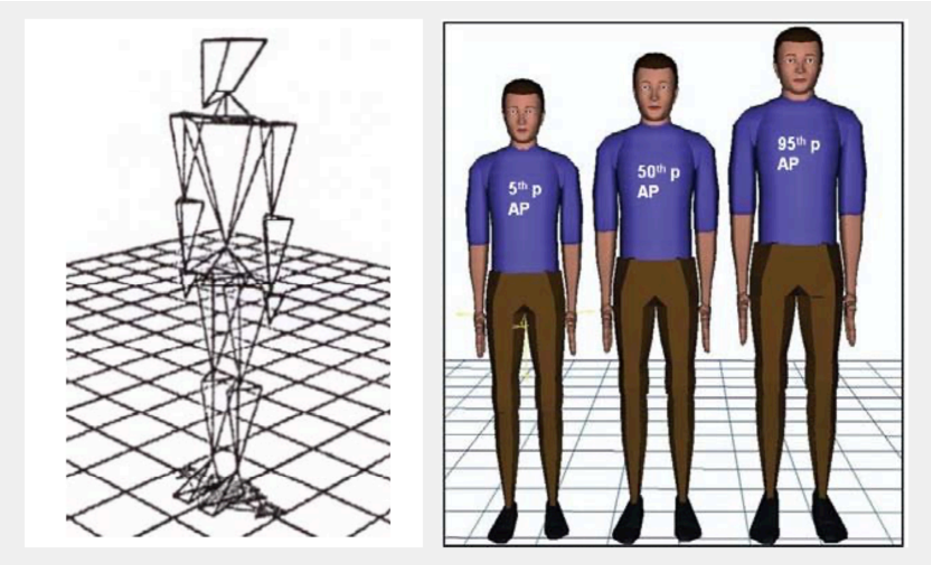


Figure12, Jack in the 1980s and nowadays.

2.2 Introduction to basic structures in Jack.

The most prominent group of elements depicted in the Jack software is an 'environment' (see figure 15) which includes figures made up of human models and objects to define a workspace. Figures can represent detailed human forms or non-living entities like furniture or machinery using a polygon mesh. A polygon mesh is a network of triangles sharing vertices; each triangle represents a polygon, forming the shape. The complexity of figures varies widely: from simple shapes like cubes— consisting of few polygons— to highly detailed models like aircrafts with hundreds of polygons. The primary element within a figure is the 'segment': segments are joined together through joints to create a flexible structure that allows easy movement.

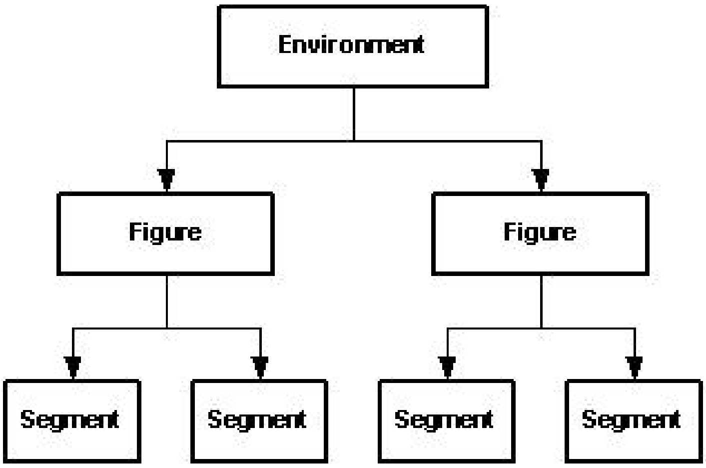
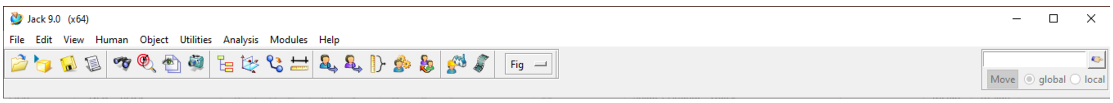


Figure 13, The Jack hierarchy

Figure 16 displays the list of different file formats that can be used to import data into the Jack environment. While bringing models into Jack, users are presented with options such as setting object position and orientation or not, displaying lines and points or surfaces only; specifying the file name and storage location in data memory space. Additional options are available on the "optimize" page for importing files into Jack — allowing more user control over what is brought into the application. To the right of these symbols is a controller that enables selected items to be moved to new positions specified either in local or global coordinates. The default setup also includes a visual display window named "TJ_Window" showing the Jack environment as illustrated in Figure 14. More graphical display windows can be added if needed to provide different views of the environment [9].



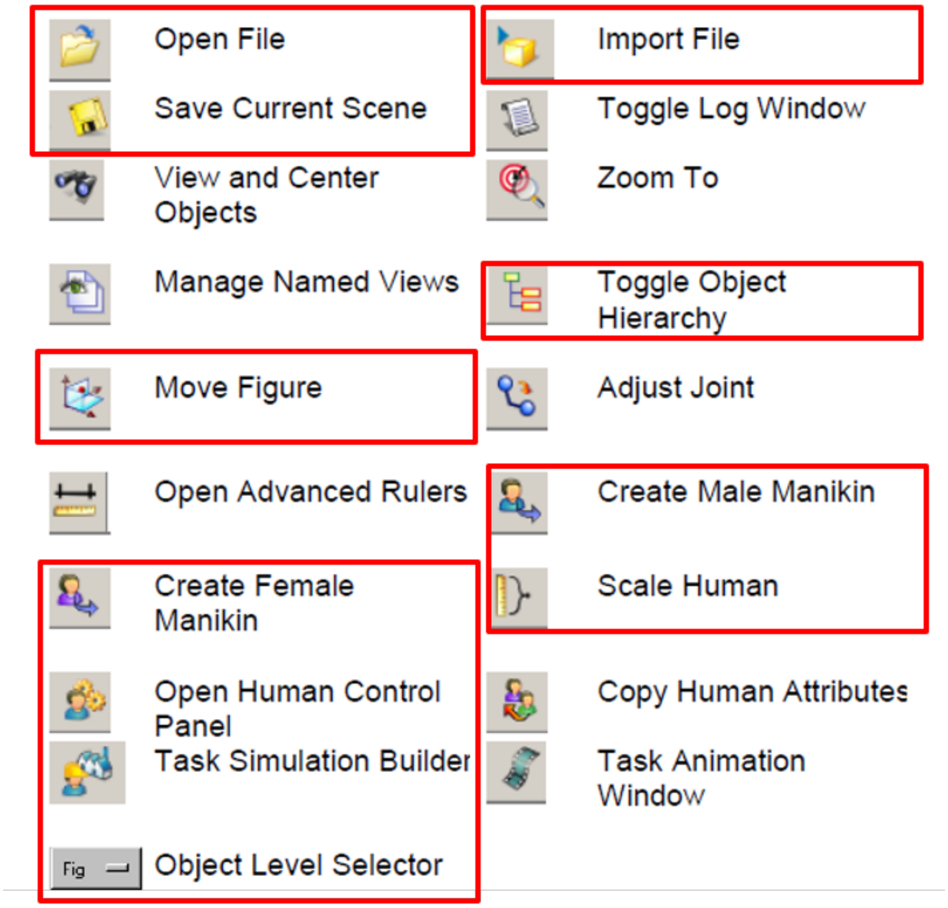


Figure 14, The Jack control bar

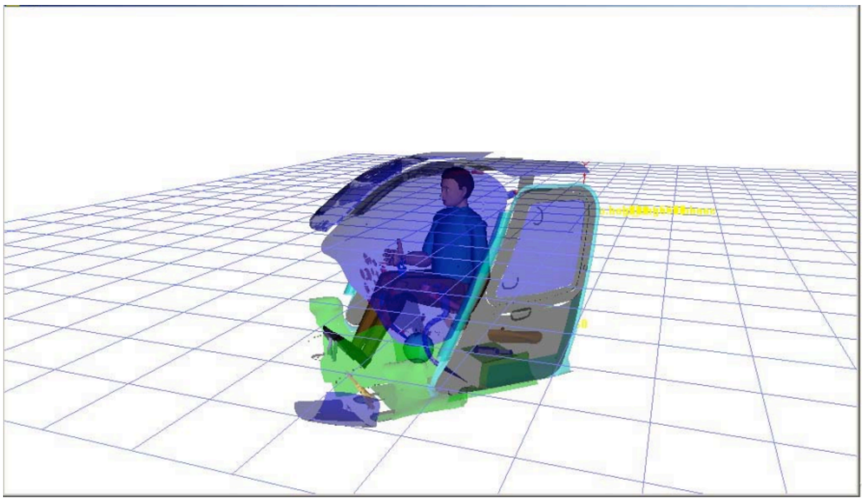


Figure 15, The Jack graphics window

Jack, through its design-based functionalities, is able to produce these basic CAD forms such as spheres, cones, cylinders and blocks which in their simplicity act as primary building blocks for more complex assemblies. Other than these basic shapes part of Jack are libraries of components like different kinds of office furniture that can be used in building workspaces. Elements can be modified through multi-axis scaling functions with nodes that are deletable and positionable; vertices whose distances from the origin can be specified or angles among edges adjusted. Components forming an object can be merged together or split apart based on user selection while modifications take place at this level. Users have three options for display: shaded, wireframe, and transparent to best represent the visual appearance of the solid object being created.

Jack, which is the subject of Figure 16, allows importing files in a multitude of formats. Upon model importation, users are given a broad range of selections by Jack — including changing the position/orientation of the object or deciding on whether to show lines and points versus surfaces only — as well as storage parameters (like file name and location). Through another page titled "optimize," more choices for file import into Jack are provided to the user.

Supported File Formats
Vis
VRML
IGES 5.3
Stereolithography
Inventor 2.1
Optimizer 1.1
Performer 2.1 binary
Deneb IGRIP 1.2 parts
Cyberware
BYU
Visualization Toolkit
Marching Cubes

Figure 16, A list of the file formats supported by Jack from web search.

Jack's human model consists of 71 segments, 69 joints (most of them are multi-axis and multiple degree of freedom), and 135 degrees of freedom. The human models are available in both genders, male (Jack) and female (Jill) [9].

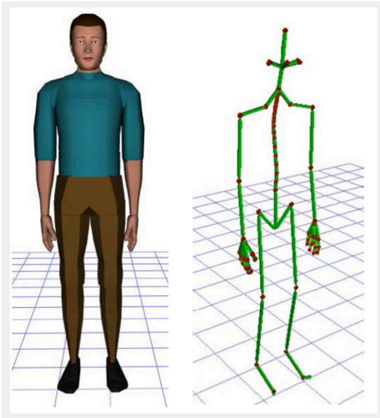


Figure 17，Jack mannequin is composed of 71 segments, and 69 joints that have 135 degrees of Freedom

Jack software presents a multitude of choices for generating human body models that are realistic in nature. Although the basic human proportions panel allows creation of male and female models based on data from the 1988 U.S. Army survey—covering a height range from 1st to 99th percentile— through more than 10 databases including US civilian, Mexico, Canadian, China, India, Germany, Japan and Korea among others plus regression equations that scale various parts of the model using average relationships among body parts to produce a proportional human body model. While such models might be useful for certain workspace design analyses, it is important to note that the population identified as "hard-to-fit" may not fall within this range. For instance, an individual with legs longer than the average proportion despite their average height might find it difficult to configure seat location and pedal position based on vision requirements and reach range for controllers due to interference by cockpit structure even when typical populations are adequately represented by these models.

The Advanced Scaling Panel also allow you for additional control over the segmented human dimensions by letting you specify a value for each anthropometric measurements of the human.

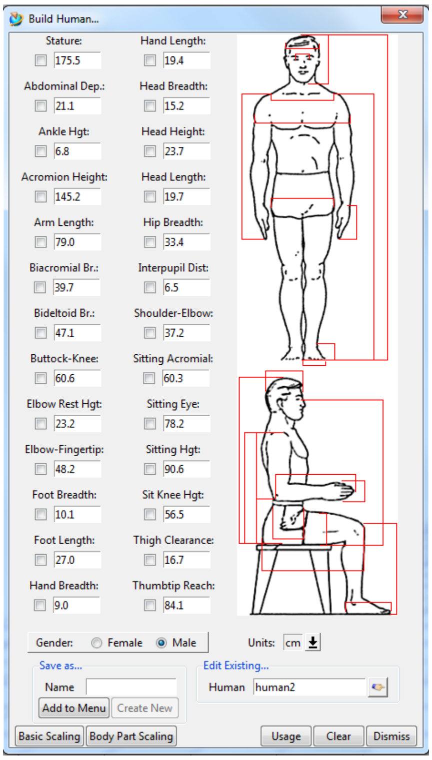


Figure 18, The anthropometric variables in the advanced scaling panel.

In Jack, the default human model in an upright position, has 69 joints. Transitioning to other postures would require adjusting all relevant joints— which could be very time-consuming given that Jack provides a posture library for improved efficiency. The library includes postures like upright standing plus relaxed standing, relaxed sitting, kneeling on one knee, driving and crawling as shown in Figure 22. Users can add their own developed postures to the library: for example, if operator posture data is collected digitally through photography or by measuring key anthropometric landmarks on a test subject— this data can be used to create a posture in Jack and saved for future use. In addition, Jack also has a hand shape library that includes hand forms such as fists, precise grasping and pointing.

Figure 19, Jack has a library of many postures and additional postures can be easily added.

The tool for human simulation in the Jack model utilizes a sophisticated system of connections between joints, thus making it difficult to determine whether the human model can attain a given posture. For example, reaching out to touch a switch on the cockpit. To simplify this process users can make use of postures preset in a library so as to approximate the desired final posture and then change the appropriate joints in order to achieve that correct final posture— or alternatively employ the human control panel: which uses Jack's inverse kinematics algorithms and under selected behavioral constraints determines how the human model moves. The behavioral constraints are used by users to act on the human model such as keeping hands or feet stationary relative to body, world, object or position or mirroring movements with opposite limbs based on these constraints. In the case of arms, users are able to define if the movement starts from shoulder or waist. The torso has the option of being fixed to keep its current direction while moving or upright position. Head and eyes have the possibility to be commanded on fixing their gaze on an object and tracking it if it is moving.

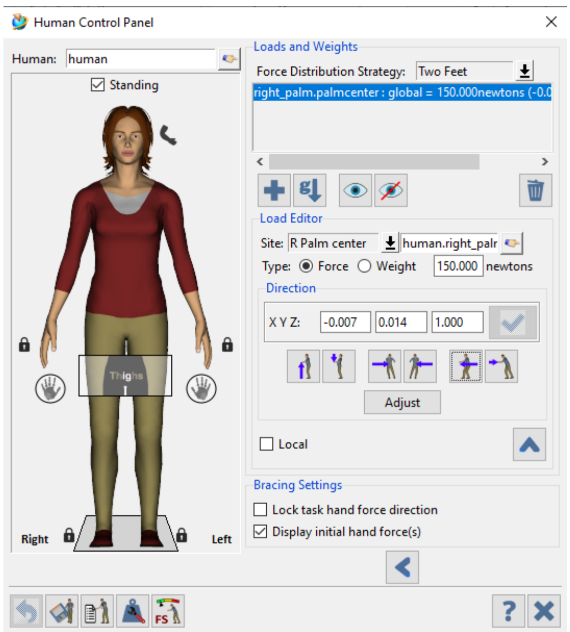


Figure 20, Human control panel in Jack.

2.3 Example of a specific operation simulation in production.

Here we use an example of a worker's operation in the assembly line:

The way in which the sequence of actions is executed consists of moving the stretcher to a position in front of the engine and fetching the oil pan from where it is placed on the pallet. The worker then lies flat on the stretcher and pushes themselves under the engine so as to place the oil pan beneath it. After sliding out from under, they stand up and go back to square one as part of finalizing completion.

The weight of the objects:

Objects:	Weight (KG)
Air intake	20
Blower locker	1.5
Automatic wrench	2
Stretcher	15
Oil pan	7

The job is performed for a normal 8-hour shift, including 1-hour break. For each hour consider the entire activity covers a 20-min period with a cycle time of 100-seconds, followed by activities not involving MMH.

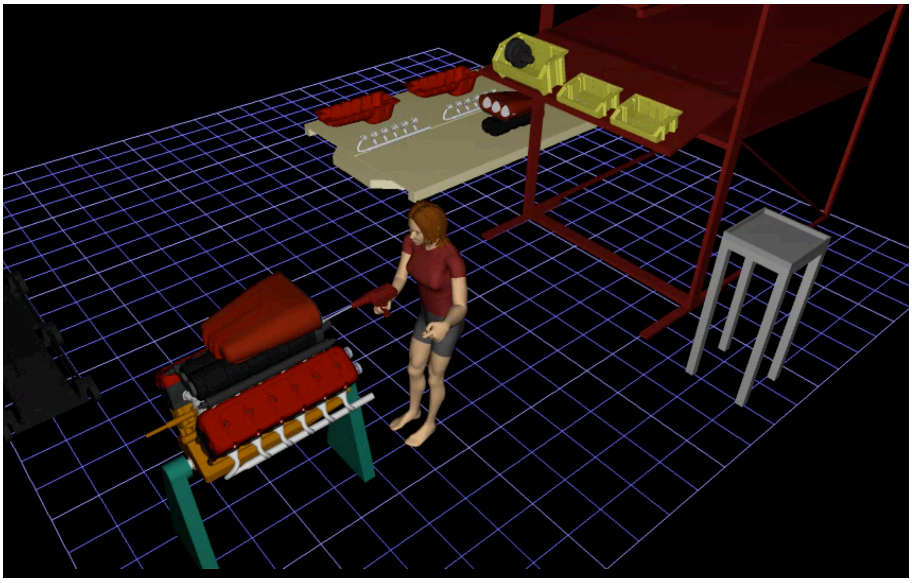


Figure 21, an example of a worker' s operation in the assembly line.

The analysis will include OWAS, NIOSH, RULA, Force Solver, etc. The main objective is to analyze the critical points of the workstation and task in order to include as much percentage as possible of the population that can perform the task without risk, and to research on further improvements of the operation to lower all the essential risks.

2.3.1 Selection of the manikin:

The field of ergonomics sees percentiles as the main concept that helps design products and environment which will suit the population intended for them. Percentiles paint a picture of how a physical trait — such as height or arm length — is distributed within a certain population. If you are at, say, the 50th percentile for height, it means you are taller than half of the people in your age and gender group. Designers find it practical to use a range from the 5th to 95th percentile; this covers most of the target users— from small to large— with an aim to make designs accommodating without causing inconvenience or safety issues. Inclusive designs are about serving needs of as many users as possible: while keeping away from discomfort or safety-related matters.

This simple yet profound idea of percentiles can be applied across all human-product interactions optimization efforts— making products more usable (by fitting user dimensions) and accessible (suitable for all potential users) without compromising safety or comfort.

P5 (5th percentile): This indicates a level below which 5% of the population can be found. From an ergonomic standpoint, it would be used in design situations that call for accommodating smaller sized individuals. For instance, when designing an automobile, the adjustment ranges for the driver's seat might be based on the P5 height so that even people belonging to the smallest 5% can drive comfortably.

P95 (95th percentile): On the contrary, it is a value below which 95% of population falls. It is used in cases where it is necessary to keep products or environments suitable for large individuals. For example, if we are talking about a car, the headroom and legroom may be designed keeping in view the P95 height so that 95% of people can fit into the car comfortably.

Using percentiles in design helps to create solutions that work for most people— with an aim towards providing comfort as well as safety and performance without any compromise.

Considering the task involving reachability and strength, we choose both P5 height and P5 weight female manikin. For trunk bending we use P95 male manikin to check the pressure risk.

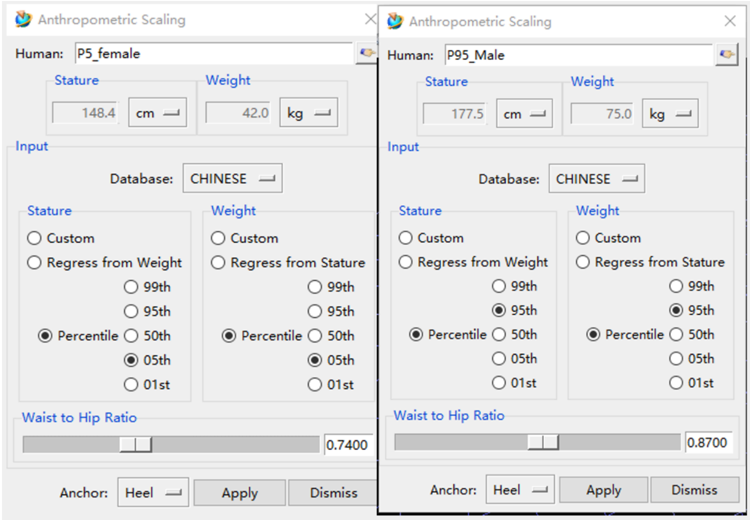


Figure 22, Choose of the manikin in this task.

2.3.2 OWAS analysis. (picking up air intake, putting air intake on the engine, moving stretcher, and moving oil pan.)

The concept of OWAS has been described in the former chapter. In OWAS analysis, we can see that most of postures have a value between 0~2, but for picking up the air intake from the table, the evaluation is 3, which suggests that this posture is risky and will cause harmful stress to the body.

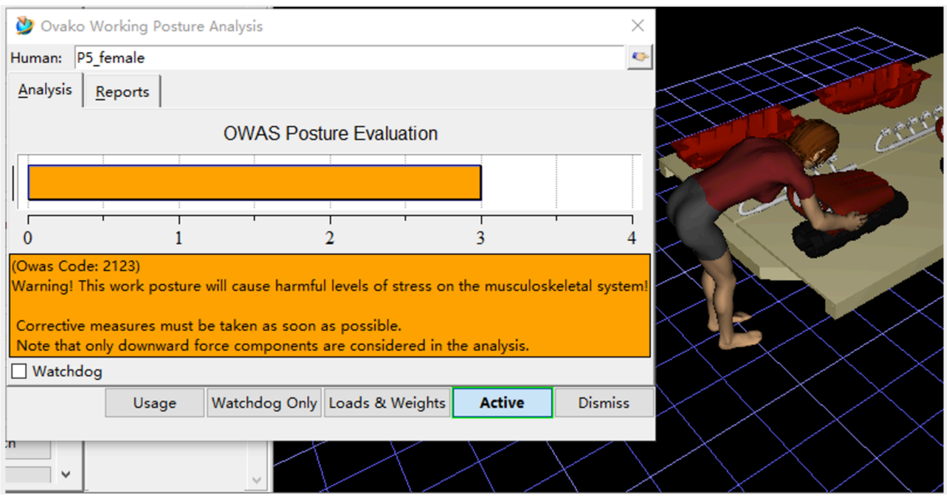


Figure 23, P5 female picking up an air intake.

The code is 2123, according to the table, for the risky posture, the back is bent, 2 arms are below shoulder height, standing on two straight legs, the load is over 20Kg.

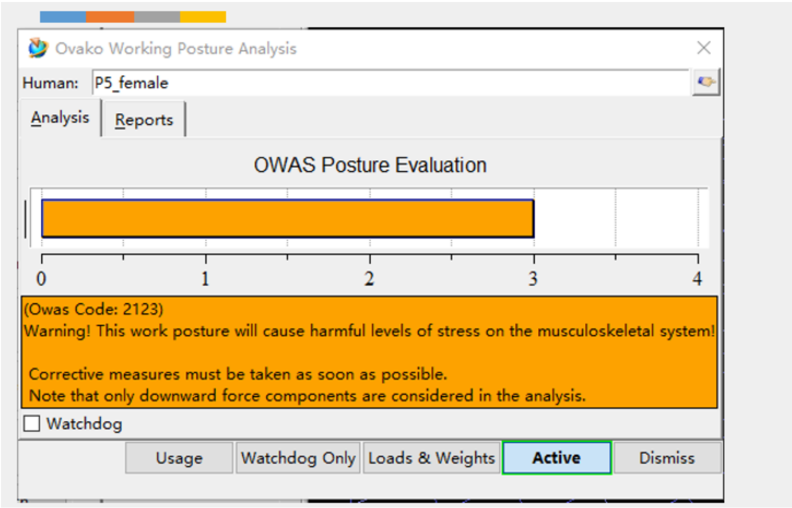


Table 16 OWAS posture/load codes

Back		*Arms*		*Legs*		*Load*	
Straight	1	2 below shoulder height	1	Sitting	1	< 10 kg	1
Bent	2	1 above shoulder height	2	Standing on two straight legs	2	10 - 20 kg	2
Twisted	3	2 above shoulder height	3	Standing on one straight leg	3	> 20 kg	3
Bent and Twisted	4			Standing on two bent legs	4		
				Standing on one bent leg	5		
				Kneeling	6		
				Walking	7		

Figure 24, OWAS posture evaluation and code table for this operation (P5 female).

For shorter workers this task risk is not with evaluation score 4, but it is still risky. In order to reduce the risk, we need a higher pallet which makes the back straight, thus the code would be 1123, and the evaluation will be lower.

On the other hand, we can see that for the same task, P95 Male manikin performs quite different from P5 female manikin, the risk is higher.

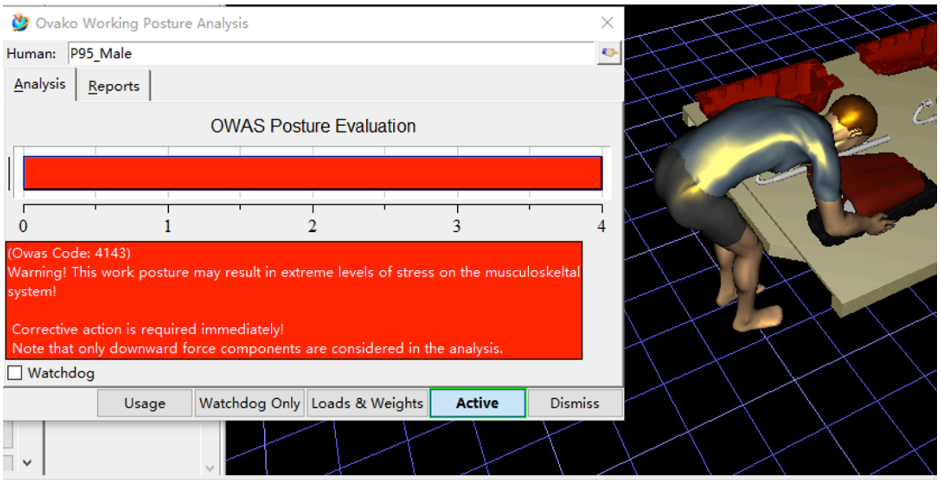


Figure 25, P95 male picking up an air intake

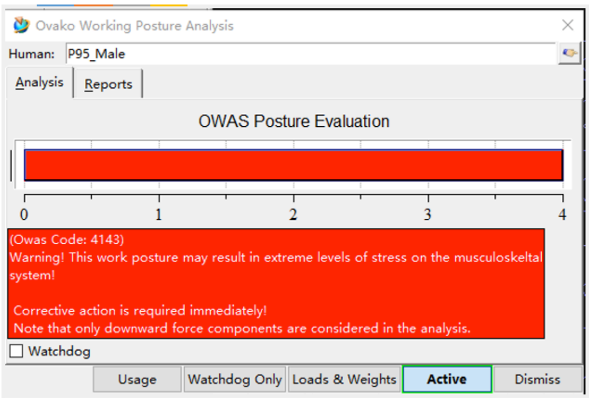


Table 16 OWAS posture/load codes

Back		*Arms*		*Legs*		*Load*	
Straight	1	2 below shoulder height	1	Sitting	1	< 10 kg	1
Bent	2	1 above shoulder height	2	Standing on two straight legs	2	10 - 20 kg	2
Twisted	3	2 above shoulder height	3	Standing on one straight leg	3	> 20 kg	3
Bent and Twisted	4			Standing on two bent legs	4		
				Standing on one bent leg	5		
				Kneeling	6		
				Walking	7		

Figure 26, OWAS posture evaluation and code table for this operation (P95 male).

For P95 Male, the code is 4143, according to the table, for the risky posture, the back is bent and twisted, 2 arms are below shoulder height, standing on two bent legs, the load is over 20Kg.

The difference is that, for P95 Male, the back is twisted and the legs are bent instead of straight. **We can say that for this posture, higher people are more risky, so we must improve according to P95 Male manikin's limits, make sure that when P95 male doing this task, their back and legs are keeping straight.**

From an ergonomic perspective, proper lifting technique that is recommended by ergonomics is the neutral spine position throughout the lift. Taller individuals have difficulty maintaining this position— because their hands are farther from the ground than those of shorter people— and are more likely to bend at the waist instead of at the knees, which leads to an even higher risk for back injury.

Thus, the takeaway point is this: taller people are at greater risk of experiencing a back injury during lifting due to biomechanical disparities which act as disadvantage mechanisms in the form of leverage effects and also implication of the Square-Cube Law [11,12]— not forgetting ergonomic challenges. These factors worsen mechanical stress on the back's musculoskeletal system, hence leading to more cases of back pain and injuries among taller individuals. Therefore, for talls who aim to mitigate these risks (with all seriousness it deserves), there are proper techniques they should adopt while lifting. Such as bending at knees and keeping load close to body— with an aim of attaining a neutral spine position and equally reducing strain on back muscles [10].

The RNLE, known as an advancement to the Revised NIOSH Lifting Equation (which estimates low back injury risk from two-handed lifting tasks), takes into account the weight of the object lifted, horizontal and vertical location of the object with respect to the lifter plus distance moved by the object during lifting. When people are taller, typically both measurements for horizontal location — taken from mid-point between ankles — and vertical travel distance — hands move from origin to destination lift — are greater which increases the lifting index value and also indicates higher risk of injury [12].

Neutral spine position is also highly recommended by ergonomic guidelines when lifting. It might be more difficult for taller people to keep this position because their hands are farther from the ground due to their height, so they would tend to bend at the waist more than at the knees which does not help in proper lifting; on the contrary, it raises additional risk for back injury.

As a final point, let’s say that taller people have more chances to get back injury while lifting because of these reasons: leverage effects, implications of the Square-Cube Law and ergonomic difficulties. These components add to the higher mechanical stress placed on an individual’s musculoskeletal back system— which in turn leads to a higher frequency of back pain and injury cases among tall persons. For talls it is very important to reduce these risks so when lifting one must bend at knees and lift load close to body: in order to keep a straight (neutral) spine position that does not strain the muscles supporting the backbone.

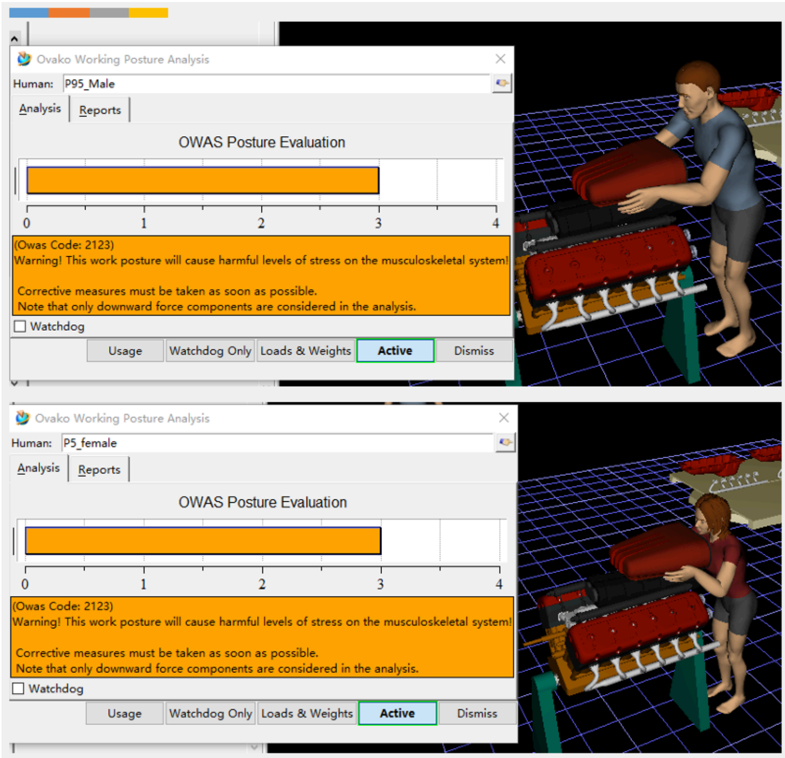


Figure 27, OWAS analysis to P5 female and P95 male putting the air intake on the engine.

As we can see in Figure 30, for putting the air intake on the engine, for both P95 male and P5 female the OWAS code is 2123, which means back is bent, two arms below shoulder height, two straight legs, load is over 20Kg, although this posture is risky, but it seems inevitable since the works must reach forward to put air intake on the engine and the mass of air intake cannot be changed.

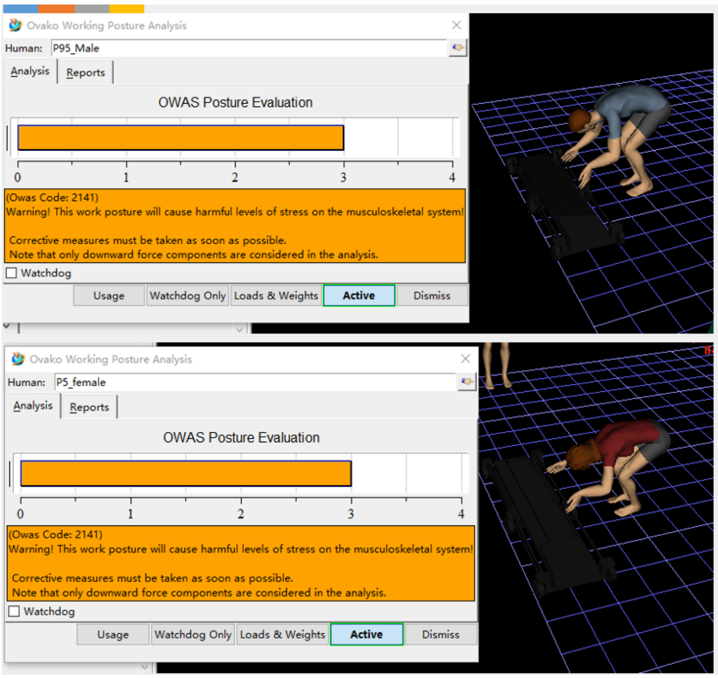


Figure 28, OWAS Analysis to P5 Female & P95 Male moving stretcher.

Moving stretcher is also a risky task, code 2141 represents the risk comes mainly from bent back and bent legs, so if there is a way to move stretcher without workers bending their back and legs, that will reduce the risk of this task. Maybe moving the stretcher only by legs while standing is a solution.

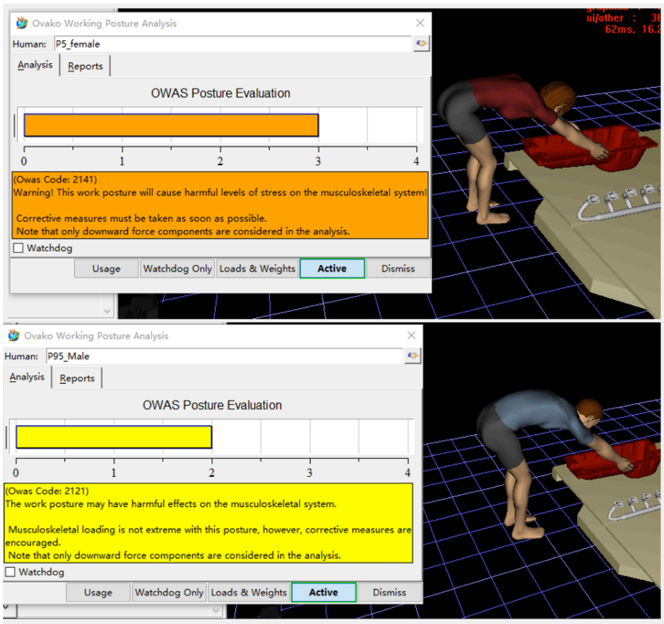


Figure 29, OWAS Analysis to P5 Female & P95 Male moving oil pan.

Moving an oil pan, however in this case P5 female suffers more risk, according to the code we can see the difference is “bent” legs, so for this task we need to consider P5 female as the limitation and use it to improve the workstation.

2.3.3 NIOSH Analysis (Air intake)

First we insert Lift Origin and Lift Destination parameters: they can be inserted manually or using Use Posture by picking the postures from the TSB frames.

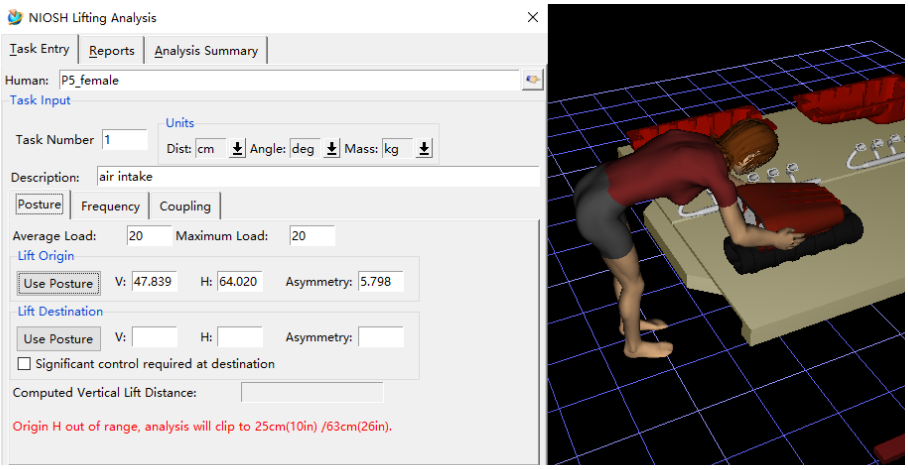


Figure 30, set of Lift Origin of moving air intake.

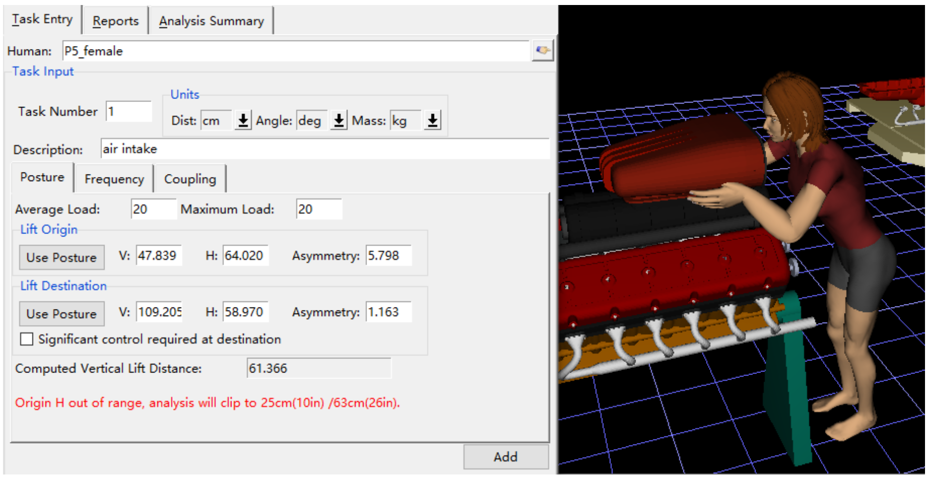


Figure 31, set of Lift Destination of moving air intake.

Then we set the lift rate as 0.6 lifts/min (20 minutes with 100s cycle time), and 5 minutes of lifting time in 15-min cycle time (because the entire activity is followed by activities not involving MMH), 8 hours work time and 1 hour recovery time, we can get the result for moving the air intake. The load is 20Kg.

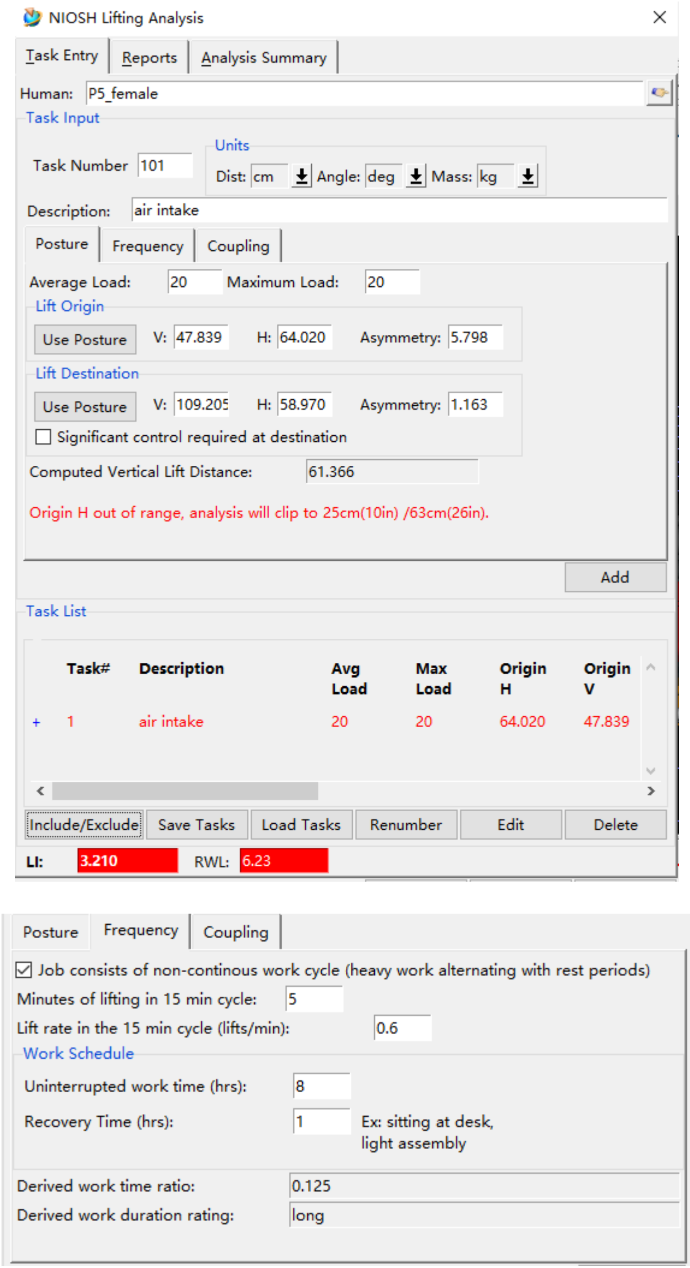


Figure 32, set of NIOSH parameters for moving air intake.

Then we will have the result:

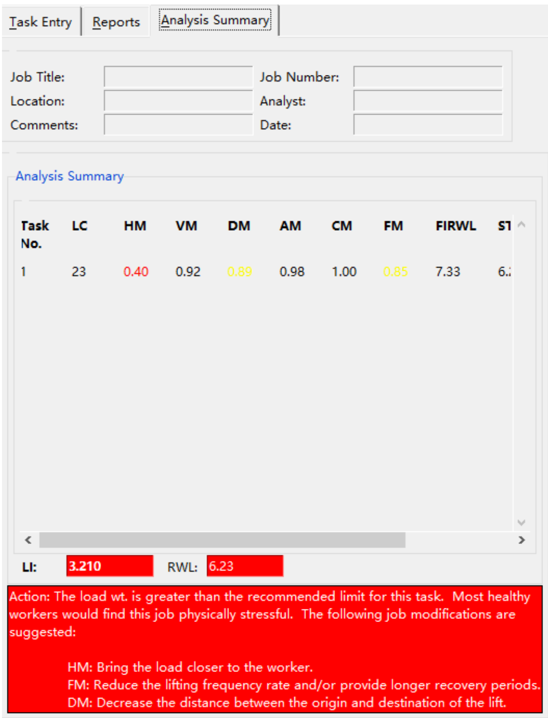


Figure 33, the results of NIOSH analysis for moving air intake.

In the analysis summary part, we can see that for moving the air intake, the risk comes from 3 multiplicators, HM (HORIZONTAL MULTIPLIER), DM (DISTANCE MULTIPLIER), FM (FREQUENCY MULTIPLIER).

If the frequency cannot be changed, then we need to increase HM and DM, which can be achieved by hands closer to spine at origin point, and decrease the vertical distance traveled (lifted).

The domain of ergonomics has seen the development by the National Institute for Occupational Safety and Health (NIOSH) of the Revised NIOSH Lifting Equation (RNLE), an assessment tool for risk of back injuries resulting from lifting tasks. The RNLE is not just any tool; it is a standout among its peers, as it takes into account many factors. Among these factors are included but not limited to the distance between hands and spine and vertical travel distance of load— noted to be high predictors for risk of injury.

Understanding why these distances, as well as the vertical travel, elevate the risk level will require developing into biomechanical plus physiological underpinnings— that much can be got from this statement alone.

Hand Distance from the Spine: The horizontal location— that is, the distance of the hands from the spine— emerges as an important determinant of RNLE. When hands are located far away from the body's midline, it increases load moment arm which is the distance between rotation axis (spine) and line of force (weight). This increased distance demands more force production by back muscles to balance out weight; such an action leads to added stress at lower back. The biomechanical principle observed here is akin to that observed in a lever: if force application point moves away from pivot point, torque produced increases. Therefore, lifting weight with arms extended laterally enhances force on spine — thus increasing likelihood of musculoskeletal disorders [12].

The Recommended Weight Limit (RWL) gives a Lifting Index (LI) that allows estimating the physical stress related to lifting tasks, from which it can be known if such stress reaches certain value then the risk of injury will increase. If there is more amount of risk suggested, it means that the hands are away from spine or vertical travel distance increases. The rule states that the LI should not exceed 1.0 for prevention of injury— according to NIOSH's recommendation as advised by NIOSH since their establishment in 1970— and has to be equal or less than 1.

2.3.4 Force solver (fastening bolts, placing air take)

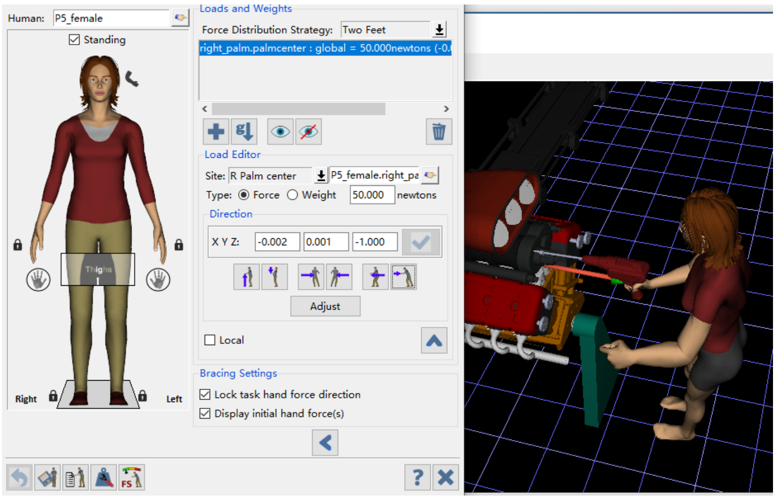


Figure34, use force solver to analyze Fastening Botls, assuming a force of 50N is applied by the right hand. (P5 female manikin)

The Force Solver forms part of the Jack ergonomics software and is used to predict human performance capabilities in tasks involving physical force such as manual handling activities. The prediction plays a critical role in ensuring ergonomic safety and efficiency in tasks requiring force, because it helps determine if a task can be done by a man based on his capabilities. The tool factors posture, reaction forces and muscle strength which help establish whether the task is within human capability. Even though weight or force of an object is not known, it provides force specifications— without prior knowledge about the weight of an object that can be used for design evaluations and 'what if' scenarios. It allows different populations' anthropometric databases to be supported so tasks can be validated across a wide range of worker groups.

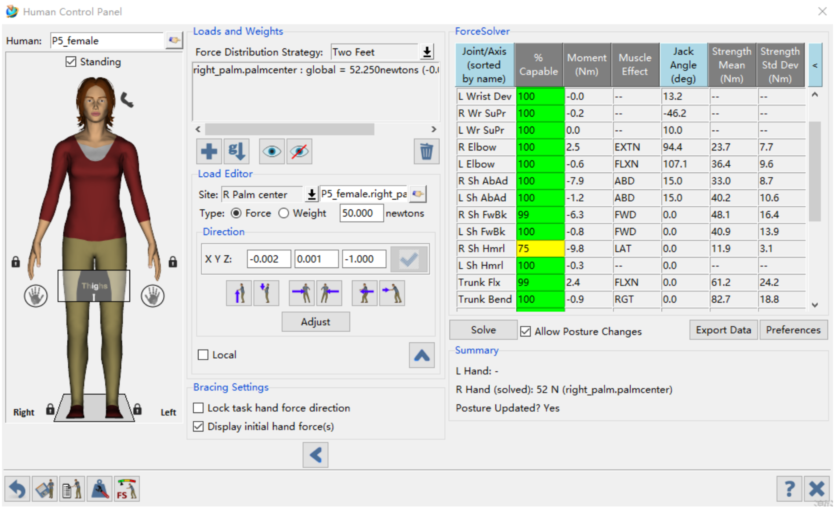


Figure35, force solver results for fastening bolts posture.

In Force Solver preference we set starting load to 0 [N] and maximum load to 300 [N]. The result is 52N for right palm, that means the maximum force can be exerted with respect to current posture and direction of application is 52N, the required force is 50N, so this action is suitable according to the industrial standard. The main threshold comes from the right shoulder.

We can also use force solver to determine the admissible design force. It allows users to evaluate and optimize the use of human strength during the design phase. This feature helps to determine the force that can be comfortably and safely exerted by the human body under specific conditions through the simulation of interaction between the human body and the environment.

Apply the assembly force on the air intake. For the direction we choose “push down”. According to EN 1005-3 standard, P15 is made for designing, so we set the threshold to 85% to determine the admissible assembly force.

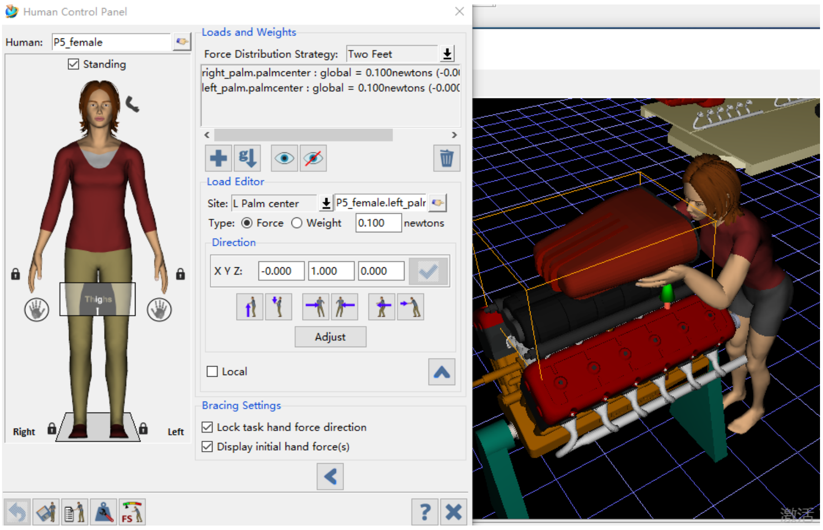
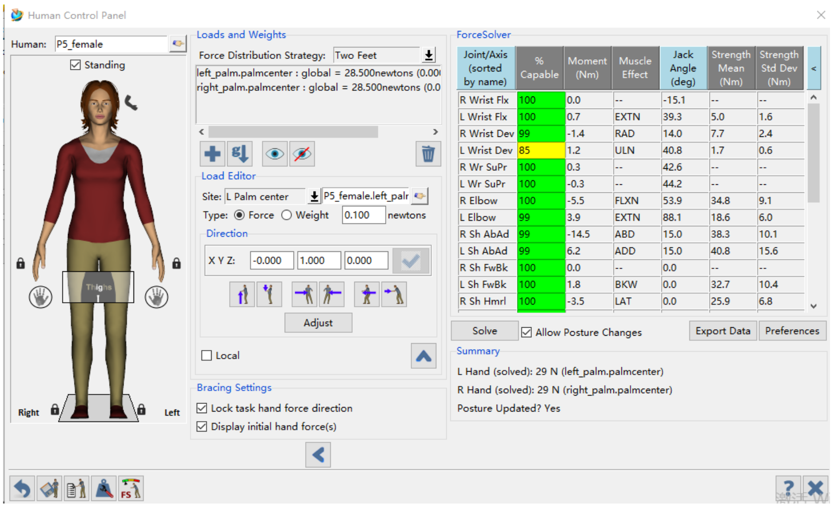


Figure36, use force solver to analyze the admissible assembly force at the design phase.



Joint/Axis (sorted by name)	% Capable	Moment (Nm)	Muscle Effect	Jack Angle (deg)	Strength Mean (Nm)	Strength Std Dev (Nm)
R Wrist Flx	100	0.0	--	-15.1	--	--
L Wrist Flx	100	0.7	EXTN	39.3	5.0	1.6
R Wrist Dev	99	-1.4	RAD	14.0	7.7	2.4
L Wrist Dev	85	1.2	ULN	40.8	1.7	0.6
R Wr SuPr	100	0.3	--	42.6	--	--
L Wr SuPr	100	-0.3	--	44.2	--	--
R Elbow	100	-5.5	FLXN	53.9	34.8	9.1
L Elbow	99	3.9	EXTN	88.1	18.6	6.0
R Sh AbAd	99	-14.5	ABD	15.0	38.3	10.1
L Sh AbAd	99	6.2	ADD	15.0	40.8	15.6
R Sh FwBk	100	0.0	--	0.0	--	--
L Sh FwBk	100	1.8	BKW	0.0	32.7	10.4
R Sh Hmrl	100	-3.5	LAT	0.0	25.9	6.8

Figure37, force solver results for placing air intake posture.

We can use Force Slover to get the result for placing the air intake, for both hands the maximum force can be exerted are 29N, so the admissible assembly force at the design phase is 2 x 29=58 [N].

2.3.5 Improvements after analysis from Jack

The most critical activity is no doubt picking up heavy objects from the table and moving it. The major risk comes from the HM (Horizontal Multiplier) and DM (Distance Multiplier), which related to horizontal distance of hands from midpoint between ankles at origin, and vertical distance between the origin and destination of lifting. So the air intake and oil pan should be properly placed which do not require a far reach distance. Thus HM can be increased and the posture will have a lower risk. And also the pallet should be as high as the top of the engine so that DM can be increased.

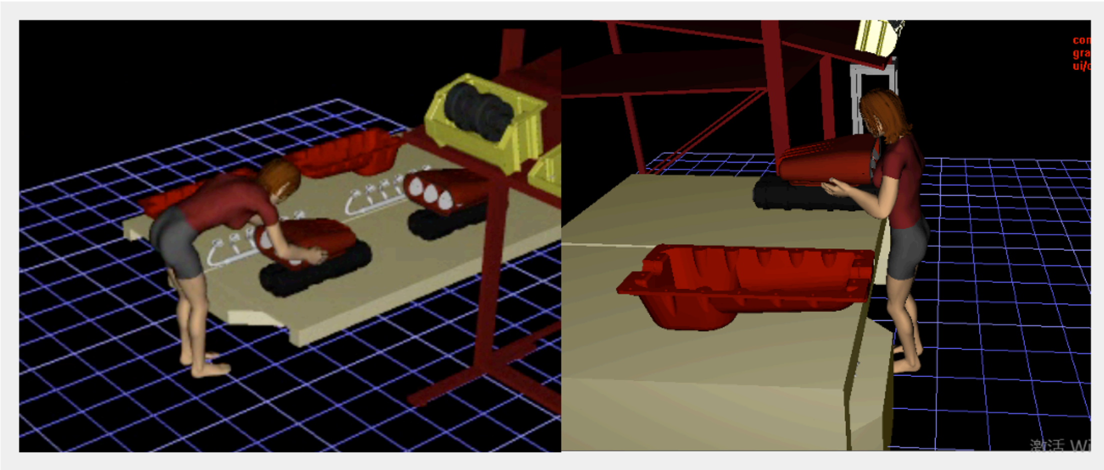


Figure38, Pallet height before and after the improvements according to NIOSH and OWAS analysis.

According to the analysis we said before, for this task, P95 male suffers more risks, so we must check the P95 male manikin. After the improvements, the OWAS evaluation becomes 1 (as shown in figure 42), the code is 1123, just like we said before. The back and legs are now straight and will not cause harmful stress anymore.

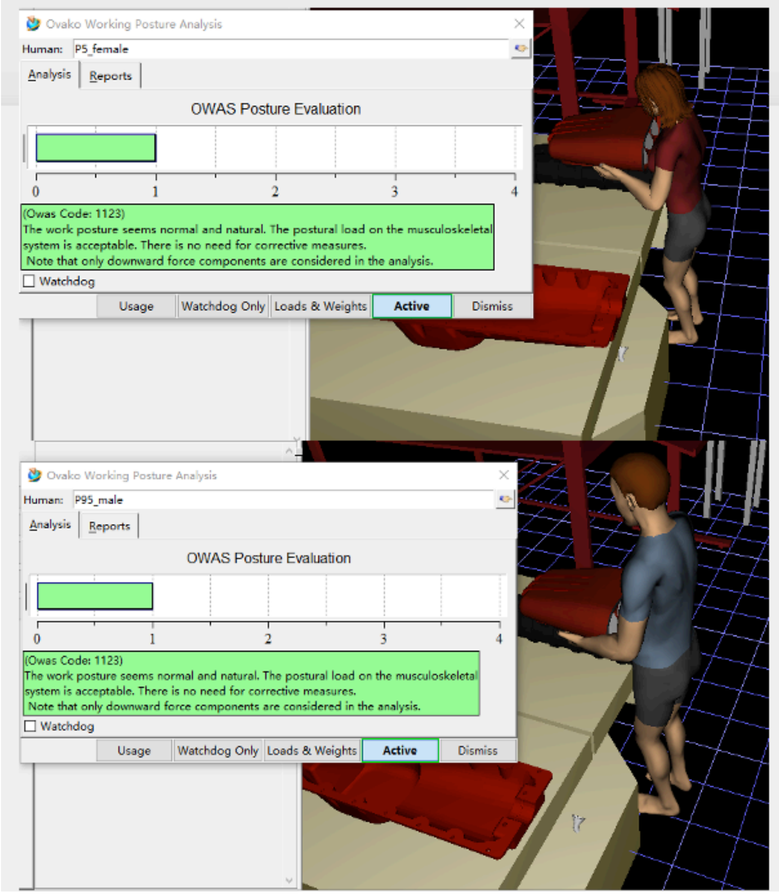


Figure 39, OWAS analysis of picking up air intake after improvements.

After we increased the height of the pallet, DM increased to 1.0, after we move the object closer to the manikin, HM increased to 0.73, thus RWL increased to 12.96 Kg, and LI deceased to1.540 (shown in figure 43).

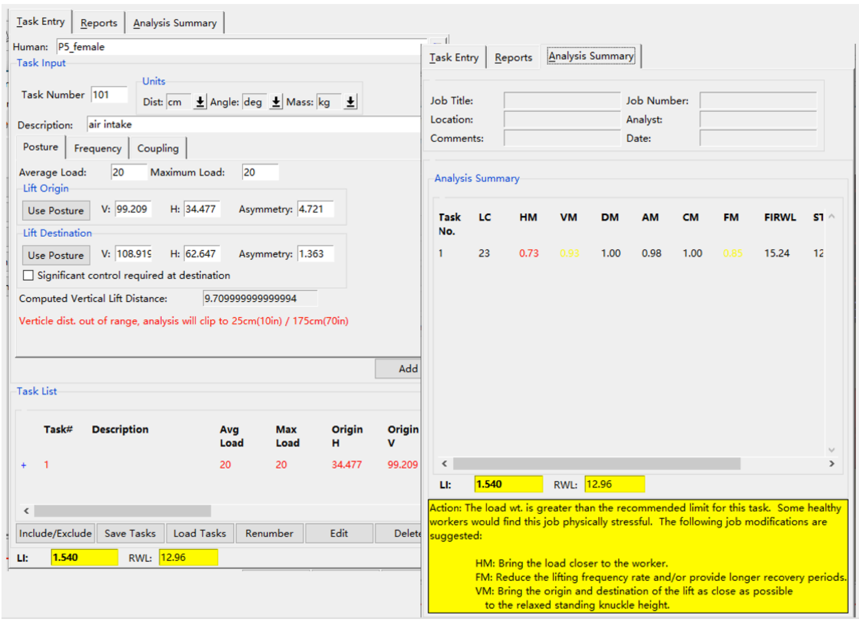


Figure 40, NIOSH analysis of picking up air intake after improvements.

Increasing the height of the pallet can greatly reduce the risk of picking up the air intake and the oil pan (according to the NIOSH analysis moving oil pan is not a high risk operation, for OWAS analysis, the results are the same as the air intake since the weight of oil pan is much lower than the air intake).

Chapter 3

3. The role of virtual simulation in the evaluation and prevention of MusculoSkeletal Disorders (MSDs)

3.1 Introduce to MusculoSkeletal Disorders.

Musculoskeletal disorders (MSD) are injuries or disorders of the muscles, nerves, tendons, joints, cartilage, and spinal discs. Work-related musculoskeletal disorders (WMSD) are conditions in which:
1, The work environment and performance of work contribute significantly to the condition;
2, The condition is made worse or persists longer due to work conditions [13].

In its classification system, the Department of Labor's Bureau of Labor Statistics refers to MSDs as musculoskeletal system and connective tissue diseases and disorders. These conditions come about as a result of physical reactions like bending or twisting plus excessive effort or repetitive motions. But note that MSDs do not include any disorders due to accidents such as slips or falls. Common types of MSDs are:

- Sprains, strains, and tears
- Back pain
- Carpal tunnel syndrome
- Hernia [14]

Carpal tunnel syndrome (CTS) is a situation where the median nerve, coming from the forearm down into the palm of the hand, is pressed or squeezed at the wrist because it passes through a narrow, inflexible ligament and bone channel. This canal— called carpal tunnel— contains median nerve plus tendons. In some cases, swelling in the tunnel from irritated tendons or other causes can compress the median nerve. This leads to pain or weakness or numbness on the hands and wrists with chances of shooting up towards your arms.

Employers face large financial burdens due to musculoskeletal disorders (MSDs). These include costs associated with absenteeism and decreased productivity. The also consist of higher health care expenses, disability costs, plus worker compensation outlays. Typically, the severity of MSD cases far exceeds that of other nonfatal injuries or illnesses.

A universally acknowledged approach to reducing workplace hazards— which also covers ergonomics— is a three-tier control hierarchy system. The first tier serves as elimination or substitution; the second tier is engineering controls; and the third tier consists of administrative controls.

Engineering Controls are the most liked by employees, and the top choice for preventing or managing Work-Related Musculoskeletal Disorders (WMSDs). It means fitting the job to the worker, which includes changing how objects are moved — using mechanical aids for lifting heavy materials or adding handles to manually carried packages — and adjusting workstations to physical reach. For instance, movable height benches or tools positioned at an arm's length.

Administrative Controls are one of the changes in work practices and policies which do not remove the hazards but reduce the risk of WMSDs. They serve as a stopgap measure until engineering controls can be implemented, or in cases where engineering controls are impractical. Examples consist of: reducing working time— limiting overtime— increasing number of breaks— changing duties (job rotation) and ergonomics programs to help employees recognize risks related to WMSDs and adopt more comfortable postures at work.

Personal Protective Equipment (PPE) acts as a protective barrier that shields the worker from potential dangers they may face. The most widely used PPE includes respirators, earplugs, safety glasses, aprons, protective footwear and helmets. Braces' effectiveness as well as wrist splints and back belts for protection against ergonomic risks is still an issue of debate; although they can reduce exposure to certain risks some cases they also create new risks by limiting natural movement in the case where wrist splints are worn during tasks requiring wrist flexion.

3.2 Data on the impact of MSDs on countries' economies.

Work ability and often work absences are majorly affected by musculoskeletal disorders (MSDs) and result in substantial costs for the persons concerned plus their families, caregivers, businesses— and eventually the wider economy. The process of estimating these costs is complicated. Multifaceted with different components that require keen attention; take for example welfare payments— such as disability benefits— which are redistributive in nature. They transfer funds within the economy without draining resources so they should be treated separately when looking at the overall cost of interventions.

To assess the financial impact of musculoskeletal disorders (MSDs), it's necessary to consider three types of expenses:

- Direct costs: They represent the entire cost of healthcare associated with the treatment of the disease. This includes preventative measures, diagnostics, therapy, and ongoing care; it also includes both public and private medical expenditures.
- Indirect costs: Those connected with loss in productivity as a result of morbidity and mortality due to MSDs are also considered. These include losses in productivity stemming from premature death or disability plus those resulting from reduced functional capacities for work.
- Intangible costs are the non-financial burdens. These include work-related psychological stress, economic difficulties, family tensions and suffering caused by health issues all which contribute to a lower quality of life [15].

3.2.1 The impact on U.S.

Annually, musculoskeletal disorders lead to approximately 70 million visits to physicians' offices in the U.S., with an overall estimate of 130 million healthcare interactions, including those at outpatient services, hospitals, and emergency departments. In 1999, close to a million individuals needed time off work to address musculoskeletal issues affecting the lower back or upper limbs. The Institute of Medicine places the financial impact of work-related musculoskeletal disorders—considering compensation, lost earnings, and productivity losses—at an annual cost of

$45 to $54 billion. Liberty Mutual, the top provider of workers' compensation insurance in the U.S., reports that injuries due to overexertion, such as lifting or throwing objects, cost employers around $13.4 billion each year [16].

3.2.2 The impact on EU countries.

Data collection constraints underscore the complexities in quantifying the financial effects of MSDs on businesses and the broader community. Nonetheless, Lundkvist and colleagues have calculated that the aggregate expense of managing rheumatoid arthritis RA in Europe amounts to approximately €13,000 per individual, or €45 billion in total. This encompasses costs related to healthcare, medication, non-medical services, informal caregiving, and other indirect expenditures. Per capita, these costs are marginally higher than those reported in other Western European nations [17].

3.3 The role of virtual simulation to evaluate and prevent MSDs.

The progress made on virtual simulation has more possibilities to the evolution plus effectiveness— in assessing and thwarting MSDs. This is achieved through combining motion capture data with digital human models (DHMs) which allows for realistic simulations of human motions. In addition, the use of biomechanical models helps unveil information on forces generated inside musculoskeletal system along with stress distribution related to different actions.

The virtual simulation method enables the possibility to do the ergonomic evaluation for tasks at work and also workplace design plus the interactions of products without any need for physical prototypes which are usually expensive or real-world trials. Digital Human Models (DHMs) are advanced computer-generated human body models that can be moved within virtual spaces to imitate motions and postures of people carrying out different tasks. This feature is very important in identifying risk factors for Musculoskeletal Disorders (MSDs), which include but are not limited to awkward postures, repetition of motion, and exertion of force.

A major advantage of using DHMs in MSD evaluation is that it helps in task analysis. This involves simulating the tasks done by workers so that analysts can identify movements likely to result in MSDs. Take an example where a DHM is used to simulate a task of lifting a heavy object; the simulation would show whether the lifting technique puts stress on the lower back, which could lead to lower back disorders.

MSDs can be kept at bay by adopting a proactive design using ergonomically fitting workplaces, tools and tasks. DHMs allow designers to come up with an optimal design even before physical implementation is done which is why this approach not only saves time and resources but also reduces substantially the risk of MSDs among workers.

Yet another remarkable advancement is the adoption of predictive analytics. Virtual simulation can anticipate possible occurrences of MSDs by evaluating vast data sets on ergonomics assessments. This technological predictive ability — under varying conditions — is highly instrumental for rational choices in organizational choice between alternative designs of work systems and manual tasks, as it allows preview into what can be expected to come up and happen.

Apart from workplace design virtual simulation is also applied to personal protective equipment (PPE) design. In this case, DHMs can be very useful in generating PPE that would fit properly and allow free motion— two critical factors for the worker's comfort as well as safety.

The challenges to the extensive use of virtual simulation notwithstanding its positive aspects are presented. One major challenge is having to possess specialized knowledge in order to operate simulation software and use the results meaningfully — an issue of proper implementation where the simulations mirror real-life situations, hence demanding constant updates in DHM refinement and parameters in the simulation.

Peering into the future, it can be said that virtual simulation has a bright prospect ahead of it as far as the assessment and prevention of musculoskeletal disorders are concerned. The evolution of more complex DHMs — due to be developed soon — alongside the progress in artificial intelligence and machine learning is expected to provide even more reliable ergonomics-based diagnostics that are also anticipatory. Moreover, VR and AR have come together on this platform which could revolutionize the approach towards ergonomic training and methods of assessment.

Virtual simulation plays a major role in the assessment and prevention of Musculoskeletal Disorders (MSDs). It offers a safe, cost-friendly plus effective way of recognizing risk factors and coming up with interventions to address them. With the evolution of technology, the potentialities of virtual simulation will only keep widening— making a greater impact on ergonomics and occupational safety.

Chapter 4

4. The evolution of virtual simulation through motion capturing.

4.1 Introduction to motion capturing

Mocap: a technology used to record the movement of objects or individuals for creating animated sequences and studying physical actions. It is widely adopted in the entertainment industry— especially in the production of films and video games— to develop animations that are realistic portrayals of characters. The way it works is that actors put on suits which have markers that help in capturing their motion; this captured motion is then mapped by animators onto digital models. In its essence, this method captures all nuances of human motion— later used to animate virtual characters with more lifelike fluidity. Apart from entertainment, mocap finds applications in sports, medicine, and robotics as well: providing detailed analysis on motion for different purposes.

There are several techniques used for mocap [18], including:

Optical Passive: This method uses infrared cameras to track retroreflective markers placed on the actor. It's flexible and commonly used due to its ability to capture complex movements.

Optical Active: Special cameras track LED markers as they emit light, providing accurate motion data.

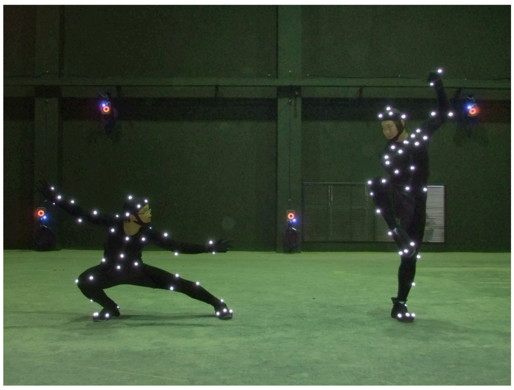


Figure 41, Mocap by Led markers

Video/Markerless: This technique relies on software to track the actor's movement without the need for physical markers.

Figure 42, Mocap by markerless tech

Inertial: Actors wear inertial sensors that transmit movement data wirelessly to a computer or smart device.

Figure 43, Mocap by Inertial sensors.

Stereophotogrammetry: This is a technique that uses photographic images captured from different angles to create 3D models of objects or scenes, which can be used to assess and compensate for soft tissue artifacts in human movement analysis.

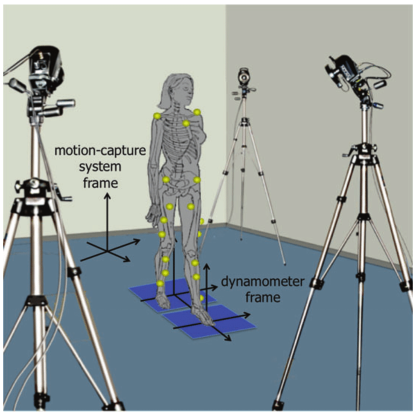


Figure 44, Mocap by Stereophotogrammetry

These methods have their own advantages and are chosen based on the requirements of the specific application, whether it's for film, video games, sports biomechanics, or medical analysis.

4.2 Evolution of motion capturing in the history

The historical evolution of human movement studies has documented instances of significant interest where challenges led to new methods of recording and studying human motions. The Weber siblings became well-known in 1836 for their pioneering scientific research that documented the temporal and spatial characteristics of human movement. Their work laid a solid foundation for future similar quantitative inquiries into patterns of human locomotion. In their time, Marey (1873) and Muybridge (1878) were among the first researchers to use photographic methods for documentation and measurement of human motion [19]. This is when Braune— an anatomist— together with Fisher— a mathematician— took up the task of recording trajectories of body segments to infer forces at joints plus energy computations based on principles derived from Newton's laws due to military motivations surrounding their work during this period, which sought to improve soldiers' efficiency in movement [20]. In 1950s, pioneering research from the University of California contributed significantly to our understanding of human motion mechanics [21].

The journey towards higher levels of understanding gait analysis has led to the adoption of new observational methods aimed at accurately capturing 3D human motion. While these techniques have their origins in innovation and are widely practiced, they require a laboratory setting and physical markers placed on various body parts. This often introduces errors into the measurements since the markers are used as surrogates for sensors. One of the major technical challenges hindering the field today is the use of skin-attached markers to provide information on skeletal movement. The marker displacements— obtained from motions of skin surface points— do not represent true joint kinematics (such as knee flexion) which must be determined based on local anatomical axes, independent segmental kinematics, without reliance upon skin marker movement due to biomechanical reasons: skin moves more than bony landmarks during motion, as it is soft tissue covering underlying bones at joints that form relative rotations[22].

4.3 Application of motion capturing in various fields

Motion capturing can be considered a tool that has many different applications at its disposal. It has helped make significant contributions to different spheres upon enabling the detailed capture of motion— thus allowing for study that in turn led to technological breakthroughs changing (for example) quality of human life, user experiences and also productivity among other sectors. In some major films such as "The Lord of the Rings" or "Planet of the Apes," where non-human characters had to be portrayed realistically (yet with human emotions) the use of this technology played a key role.

Figure 45, Movie "Planets of Apes" using Mocap

Mocap, used in gaming to produce animations that are very close to real life by recording object or people movements. It enables the development of more believable and absorbing virtual worlds— which would otherwise be unattainable— thus greatly enriching the user's experience. The way it works is that game developers employ mocap to take note of elaborate human body actions. These notes are later used as models for characters' actions while playing.

Figure 46, Mocap in Tomb raider.

Industrial sector is an area where mocap technology is used for creation and testing of new products. It aids engineers and designers in visualizing the work done by people with machines, which can help improve ergonomics engineering: that is to say ensuring that technological design takes proper account of the interaction between them (making machinery safer and more comfortable for humans). Mocap also finds use post-production during manufacturing to monitor laborers' activities based on assembly lines; such analysis helps ensure high output by detecting any idle workers or inefficient work.

Figure 47, Mocap application in assembly line

Medicine is one of the fields that has significantly taken advantage of mocap technology. It helps in studying human locomotion and other movements which enables physical diagnostics in many pathologies. In creating those programs, health personnel use real data on patient movement — captured by mocap sensors — leading to more effective rehabilitation. Mocap is also used for planning surgical operations and producing prosthetics: it guarantees the proper fit and natural mobility, thanks to the information based on motion capture. The area of sports medicine benefits from this as well since it allows athletes to be better at what they do (the analysis of motion mechanics) and prevents injuries through optimization of sports technique based on motion capture data.

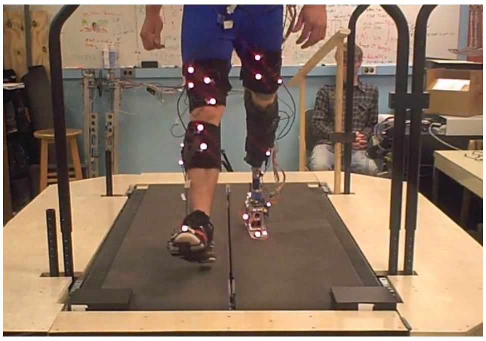


Figure 48, Mocap in medicine field

All things considered, motion capturing is a versatile resource that has brought meaningful advances to different sectors— which in turn has resulted from its ability to faithfully capture and study motion. Such innovations have been able to have direct impacts on the quality of life or the enhancement of user experiences plus even increased efficiency in various fields. As we move further into the technological age, the potential uses of mocap — and the possibilities they hold for further integration into our daily lives or work — are only going to grow with more future applications sure to come down the pipeline.

4.4 An example of motion capturing in industry-Ford Motor Company.

"We call assembly line workers 'industrial athletes' because their jobs are so physically demanding," said Allison Stephens, Ford technical director of assembly ergonomics. "Through ergonomic testing, we make data-driven decisions. A safer vehicle production process and better protection for our employees." The virtual manufacturing team at Ford works years before the launch of vehicles and uses simulations that allow them to review how the car is put together so they can identify any issues that would lead to worker fatigue or injury during actual production; thus they ensure designs are pragmatic while also safeguarding their workforce.

A complete body motion capture system that follows over 5,000 different points of data for the purpose of ergonomics research, which is similar to the way sports performance is optimized and injury prevention is accomplished. In the space devoted to assembly, the method of hand fitting is evaluated through feedback from real-world experiments instead of virtual experiments that use 3D printing. A virtual reality setup that is steered by a 23-camera system allows employees to visualize their future work stations prior to checking if the task is appropriate for their skills or not. The integration of these technologies promotes more efficient design methods plus safer working environments.

Ford has had its ergonomics team assist in over one hundred vehicle launches globally using virtual tools such as the 2015 Mustang and 2016 Explorer. The purpose is to improve safety and effectiveness. As a result of substantial investments made, there has been a sharp decrease in ergonomic-related injuries: reaching up to a 90% reduction in cases involving overextension or difficulty during part installation. The leader of Ford, Michael Torolski underscores the organization's focus on healthy working environment by these technologic processes that decrease injury and thus validate new production technologies [23].

Figure 49, Mocap used by Ford Motor.

Chapter 5

5. The virtual reality tools in industry field

Virtual reality (VR) technology is an innovation that permits individuals to have dealings with a graphic, artificial environment that exists in three dimensions. Through the use of VR headsets plus gloves and body suits users can come into the virtual world and be able to manipulate it. These equipments provide visual and auditory feedbacks— sometimes also haptic feedback — thus creating an environment where user is immersed in.

5.1 Virtual reality technique and its characteristics

VR has interaction techniques which are crucial for an immersive experience and includes actions like selection, manipulation (like data gloves), and locomotion [24]. They allow users to interact with the virtual environment in natural ways.

Selection is the process of indicating to the system the specific object or user interface element that the user intends to engage with. After the user has made a choice and confirmed it, the chosen item becomes the one on which subsequent interactive commands will operate. There are different ways in which this act of selection can be done, for example through use of a controller or making hand movements or gazing direction.

It is likely users would want to change its properties by altering its size, orientation or position. The primary modifications involve scaling the chosen item— rotating it or moving it to another place on the screen. Various interaction techniques facilitate each particular modification with a choice of a method based on the input device's capabilities. These capabilities are determined by the type of input device and may vary from basic devices like a scroll-wheel or touch-pad to more sophisticated bimanual interactions that include pinching and stretching as input actions.

User movement in a digital space refers to different ways of locomotion. This particular component is key in virtual reality design as it greatly influences both the user's sense of being immersed and comfortable while in the VR environment. Some techniques are:

Teleportation: Users can move instantly to any point within the virtual world using this technique. Though it helps reduce motion sickness, it might decrease presence illusion.

Artificial Locomotion: This group includes gliding or soaring — methods where movement is controlled through VR interface and not by actual physical user gestures.

Physical Locomotion: This method mandates users to act out physical movements, like marching on the spot while navigating the virtual space. It tends to offer a more engaging experience but might require additional equipment such as VR treadmills.

VR is commonly known to be experienced through a helmet with a dual-screen — displaying artificial animations in such a way that it mimics real life. The user would then feel telepresent in that digital space because motion detectors, which are installed inside the helmet and can detect any movement made by the user physically, work hand-in-hand with the display system. The role of the motion detectors is to ensure that whatever change occurs as a result of movement from the physical person, like turning or bending, is mirrored onscreen. This results in a setup where users are able to virtually navigate rooms based on their physical steps since views are changed based on head position and direction. In addition to this setup: individuals wear data gloves with haptic feedback mechanisms so they can have a tactile perception— being able to feel weight, shape and texture (for example stiffness) about virtual objects.

5.2 Application of Virtual reality and future trends

Virtual Reality (VR) has a diverse array of uses in multiple disciplines including automotive, healthcare, retail, education, architecture and urban design, entertainment and military.

virtual reality is a revolution in healthcare that creates an inmersive environment that enhances the care provided to patients and the training of healthcare professionals, this enables the sector to utilize innovative methods. In diagnostics and treatment, 3D-VR provides doctors with a visual experience of medical conditions in a 3D space that is difficult to understand from a 2D screen, this benefits the understanding of anatomy or pathology as well as the practice of surgery. It reduces the time of surgery by practicing complicated procedures on a virtual platform and therefore decreasing the number of operations needed, with a more successful outcome as well[25]. However, few studies focused on the implementation frameworks, specific strategies, goals or results. However, to bring the implementation ofVR in healthcare to the next level and make sure that this implementation will not be limited by a single study that focuses on one aspect (like the barriers associated with therapists) it is crucial to examine the entire process. The procedure should start from recognizing barriers, and end on the development of a consistent, multistage implementation strategy with appropriate strategies, clear goals, and pre-established results based on a framework that focuses on behavioral change in regards to healthcare providers, patients, and administrators. This would facilitate the use of virtual technology in healthcare by increasing the acceptance of the technology among those involved in service delivery, this would subsequently lead to an increase in the utilization of the technological component of the device. [26].

In the business realm, virtual reality helps create shopping experiences beyond physical space limitations where customers can freely navigate virtual showrooms and try on clothes using digital fitting rooms; they can also see products placed in their own living spaces before deciding to buy them. Such technology leads to more than just improving customer experience. It empowers retailers with actionable intelligence on consumer behavior and choices, thus by using VR the retail industry customizes such sophisticated experiences that allow brands to form stronger relationships with customers.

Virtual Reality goes beyond the mere visualization of architectural designs. It is leading to the establishment of a new order in the construction industry where it serves as an effective tool for both architects and clients. With VR, architects can create detailed 3D models that allow them to virtually enter into the design— hence being able to have a feel of the building even before it is constructed. This immersive technology provides better spatial understanding plus visualization unlike what traditional 2D blueprints or physical models would offer. On the other hand, clients can take virtual tours for their future homes from which they can draw practical perceptions of space; this leads to more informed decision-making leading to higher satisfaction post completion of the project.

Virtual Reality finds extensive use in military field. It includes but not limited to combat training, vehicle and aircraft operation simulation, medical training & psychological therapy (e.g., PTSD) that help in enhancing soldiers' readiness and effectiveness through provision of realistic yet controlled settings for practice. This is made possible by the technology's feature to simulate complex situations which enable the military personnel to go through different challenges and be able to respond appropriately without risks that come with live exercises.

The prospects for VR technology's future development are indeed very bright, and major breakthroughs can be expected in many fields that reach a vast scope. As the display and sensor technology marches forward with giant strides, VR user experiences will take a leap towards realism— providing higher resolution images plus more precise motion tracking. The social sphere will not be left behind; VR platforms are poised to support richer social interactions that allow people to communicate and collaborate in new ways in virtual spaces. Remember carrying heavy VR gear? Not anymore. Future VR devices will be lighter, wireless, and standalone — ushering us into an era where virtual reality is truly devoid of any physical connections or limitations.

In addition to this standalone growth trajectory, integration of VR with AR and MR will create a mixed reality experience that users have never witnessed before: blurring boundaries between the real world and the virtual one. Keep pace with these technological strides because soon— sooner than we realize— VR will knock at every door as an uninvited yet indispensable guest offering experiences galore, opening doors hitherto unopened for opportunities that were unthinkable.

5.3 An example of virtual simulation in industry - General Motors.

The current studies conducted at the Global Ergonomics Lab of General Motors involve Virtual Reality (VR) sessions using Process Simulate. The aim is to ensure that the design and manufacturing engineers gain a deep understanding of designs in a 3D environment. Human reachability, line of sight for the operator, machine accessibility, and surrounding area from which other parts can be operated or reached easily including hand clearance space are some of the main points addressed during these studies. Instead of physical human simulation studies, using immersive technology complements them— this not only improves safety workstation designs based on findings during vehicle development but also fosters better collaboration between product engineering and manufacturing engineering thereby reducing late design changes in the product lifecycle [27].

The simulation features the Process Simulate “live hands” module that offers a detailed view of manual assembly and hand clearance. Real-time measurements can be taken using an interactive ruler on the scene. Audience attention can be drawn to issues noted via markup capabilities, while notes can be taken (and used for issue tracking) to capture details about the issue description with accompanying screenshots for documentation.

The simulation includes Process Simulate “live hands,” an integral part of manual assembly and hand clearance. Real-time measurements can be taken using the interactive ruler that appears on the screen— markups can be used to point out any issues identified for the audience, who in turn might want to take notes with a description of the issue captured or document it with a screenshot and saved along with all related data [27].

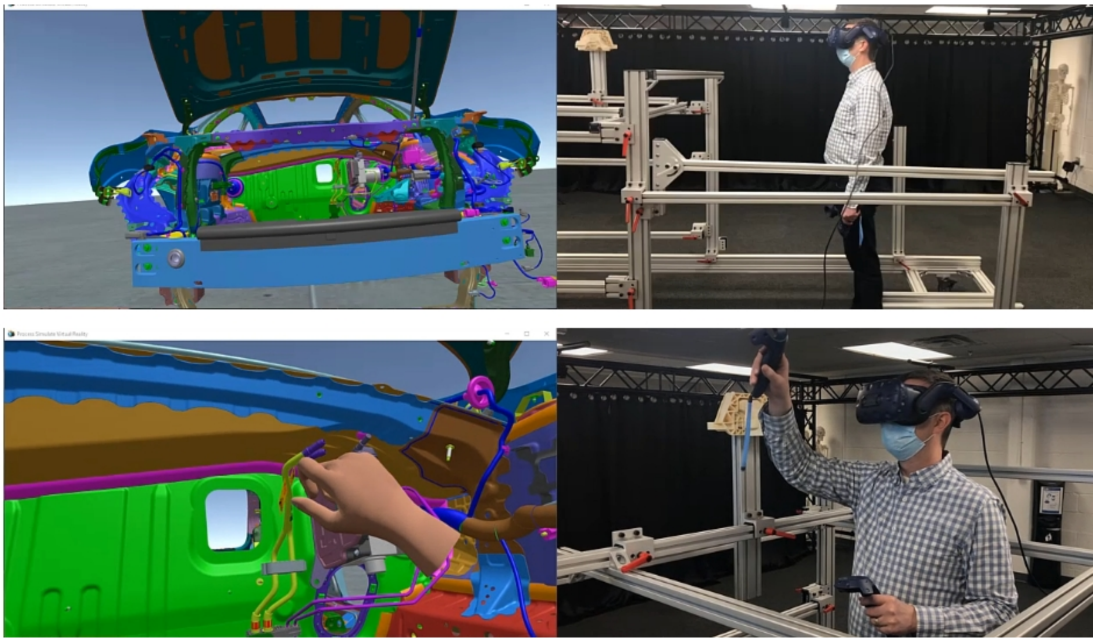


Figure 50，GM uses physical mockups, 3d printed parts, and VR to improve ergonomic assessments.

The team responsible for the GM employs motion capture technology in the process of simulating processes and analyzing ergonomics. They document the motion of a female technician that is passing through an impact region into the engine room. The comparison of sizes is accomplished using the larger male's motions to ensure that different body sizes can be accommodated well in the space while also taking into account the necessary clearances and postures for future operations, as well as the physical interactions with structures via motion capture (and 3D printed models). Backward analysis is employed to investigate low back stress plus awkward postures; the findings are stored in a posture library for future reference or use on a different case study.

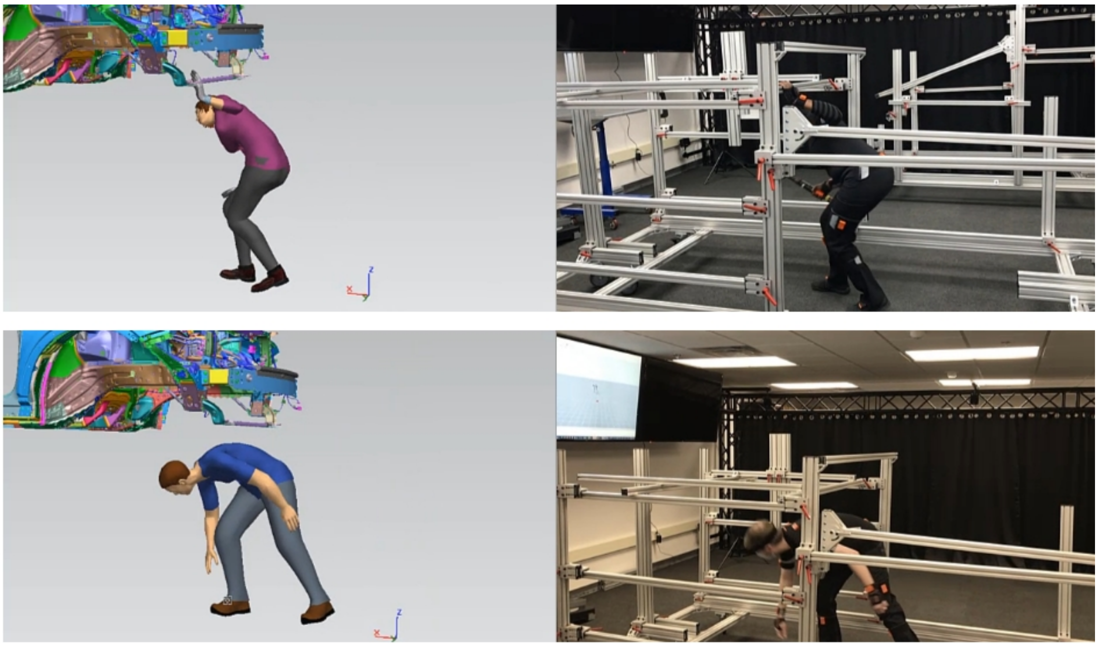


Figure 51, VR with motion capture eases the comparison of multiple anthropometries for a particular operator task.

In addition, the surge of VR technology facilitated collaboration among General Motors when the remote work increased. It established a safe and efficient online communication for top personnel like designers and engineers using Microsoft Teams or Zoom, which allowed virtual presentation during meetings thus eliminating need for physical mockups that were to be reviewed by plant members at site on new vehicles. The increase of VR led to decrease in physical mockups through production floors; an engineering prototype would be done virtually so all plant members could also see it remotely hence discussion facilitation and ultimately streamlining design and engineering processes.

5.4 Another application of Apple Vision Pro in Porsche AG.

Apple introduced the VR wearable Vision Pro early in 2024. This move was important for Apple to make as it moves into high-performance and mobile wearables but Vision Pro did not attain the same success other Apple products have did. The cost of Vision Pro is very high— reaching 4,000 euros in the European Union—

which limits its popularity among ordinary consumers due to unaffordability. The offerings in terms of quantity and quality of VR content are still limited and do not cater to consumer needs. Network latency plus dizziness from improper gyroscope data also reduce the quality of VR experience.

But Vision Pro has shown favoritism in the automotive sector. Porsche and MHP, for instance, use Apple Vision Pro in industrial training and production training at the assembly line of high-end sports cars. Its uses involve 3D training among employees which leads to reduced production costs as well as more interactivity.

Management and IT consulting company MHP, in cooperation with Porsche AG, is taking training in the field of industry and production to a new level: In a demonstration, parts of the production process in a plant were realized in the form of highly realistic 3D training in Apple Vision Pro.

In the "Workshop Training" demonstration, the CAD data of the robot and the rotary table (welding) are realistically displayed in Apple Vision Pro. Thanks to the capabilities of Apple Vision Pro, employees now have an innovative training application that not only saves time but also makes the training very effective due to the realistic reproduction of the production system.

For example, shutting down an entire production facility for training purposes is costly and can cause delays in the entire system which could been prevented by using VR technology. On the other hand, training with Apple Vision Pro can be carried out at any location. In the specific demonstration developed by MHP, employees in the workshop immediately see the entire task they have to perform step by step. In addition, detailed repair instructions are displayed using 3D models. This reduces errors and increases employee satisfaction. Personalized time recording, evaluation and training certification are also possible, for example by evaluating the sequence of steps and parts and maintaining the correct distance to the robot.

“Apple Vision Pro enables us to develop solutions for our customers that can be displayed in an extremely realistic digital environment. This leads to a considerable increase in efficiency and cost savings," explains Markus Wambach, COO and Member of the Management Board at MHP. "The detailed and realistic training courses and sessions that we can develop for our customers will increasingly cut out costly errors. This is because the up-to-date information that employees need for their work is displayed right in front of them as they carry out the task. This not only helps us to become much more efficient in our work, but to create a better working environment, too." [28]

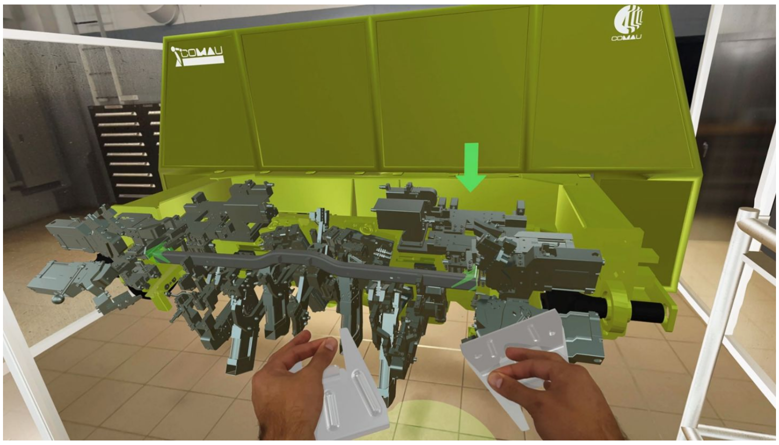


Figure 52, Application of Vision Pro in Porsche plant.

Employees acquire safety knowledge during the process, which can be enhanced with fun components or Gamification to attract younger employees. Because of the system's continuous association with the Apple ecosystem, the integration of Apple Vision Pro with the existing infrastructure is easy. The intuitive user interface, obvious display and straightforward user experience of Apple Vision Pro makes it the ideal platform for the training of Porsche.

Chapter 6

6. Future trends of virtual simulations in industry

The use of virtual simulations would change the way different industries function by providing unmatched integration and realism. Future trends suggest that organizations will move towards immersive virtual worlds that are able to create real life situations in a very realistic manner, which means the adoption of VR simulations will be on the rise as well, it is expected to be primarily fueled by the advancement of VR technologies and growing need for effective training solutions and cost reduction.

In the manufacturing sector, Industry 4.0 has led to the creation of virtual experiments that have never been seen before.

In the manufacturing area, Industry 4.0 has created virtual simulations like never seen before. Predictive modeling and simulation, digital twin technology, and immersive virtual digital factory simulations are now part of the production system which allow visualizing whole production lines and fostering human-robot cooperation in the work floor, these make factories more effective and flexible.

The convergence of AI and machine learning with simulations revolutionizes the space. AI is capable of speeding up simulation processes in a major way, thus allowing analysis and decision-making to happen in real time— which is most useful in areas where quick prototyping and design iteration are important. The adoption of digital twins can bring the virtual world closer to the real world: it creates an exact replica of a physical system virtually, thus establishing an environment that is highly dynamic for testing, analysis, optimization since any changes made will be reflected instantaneously on the actual system.

Simulation employs AI to analyze information and predict what will be most effective in the future. AI derives data from your operations and provides you with information about what to simulate or what to avoid. AI can acquire data from simulation results and help direct subsequent steps, for example, which parts should be altered or multiple parts should be altered.

AI has the ability to assess idle production periods in factories and come up with consumer demand-creating targeted marketing campaigns for a product to be manufactured during this time lag. Such an approach would enhance effectiveness which ensures output is optimized at all times within the production system leading to maximum profits.

Utilizing a predictive AI enables the analysis of historical data from machine-installed sensors to identify operational anomalies and forecast future failures. This would result in situating industrial entities in positions to plan maintenance work at points where machines are most likely going to demand or experience unscheduled downtimes. If predictive AI in a factory system could predict in a certain time that the machine or system would have a breakdown, it can recommend effective measures, like machine parts replacement, changing of tools, that can significantly prevent the risk from occurring.

AI is set to significantly change the allocation of employees' time in future work scenarios, where more than half of it is still used for administrative work by converting this into innovation time that constitutes only around 7% at present.
A different way in which AI will significantly modify manufacturing and the labor force is through skills. Major retraining— as data indicates by 2030, because of the skills gap, there could be millions of job vacancies— is something that businesses have to lead. The global workforce, maybe half of it, would need retraining: this would force employers to provide training opportunities for all employees.

Chapter 7

7. Conclusion

Virtual simulation — an indispensable cost-effective means of ergonomics. A method through which workspaces can be designed at a low cost and favoring the healthy human living, it allows for analysis of optimization of man's engagements in his systems— on its own level boosting productivity while curbing injurious work-related cases. In the realm of digital human modeling tools, JACK software shines bright as it assists greatly in improving ergonomics from product design to workplace safety; by simulating tasks involving humans and carrying out analysis in virtual environments, it aids in early identification of potential issues regarding ergonomics. The contribution of virtual simulation to Musculoskeletal Disorders (MSDs) prevention cannot be downplayed. Tasking real-world activities replication plus ergonomic risk factor analysis helps come up with interventions aimed at addressing these MSDs impacts both at individual level and economy-wide. The industrial applications of motion capture technology are in the control of robots, additive manufacturing and enabling remote work. These applications enhance productivity and safety at work. Virtual reality is an immersive technology that can foster industrial processes optimization and skill enhancement among employees through using virtual training programs and design evaluations. In the future, various sectors will be greatly changed by AI technology. In industry, the convergence of AI and simulation technology fosters enhanced adoption of real-time analysis and decision-making— while digital twin technology closes the gap between the physical world and virtual world. Predictive AI is likely to be adopted in factory production to optimize output through maintenance of production lines that would otherwise lead to breakdown or accidents during the manufacturing cycle.

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