

# *A more realistic Digital Human Modeling (DHM) approach to manufacturing industry*

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**Abstract** — Today's globally competitive and challenging market place places demands on workers to perform at their best. Workers may have to struggle and maximize their efforts to meet the demands of modern manufacturing systems. Often, excessive workloads due to high production targets cause serious problems for the workers in the form of pain, injuries, fatigue, slips and falls. All these problems result in job dissatisfaction and the organization suffers from a loss in productivity and quality. In this globalized world, the diversity of organizations' workforces is increasing with every passing year. In this context, it is challenging to propose suitable design solutions that can accommodate the maximum percentage of workers. Previously, Digital Human Modeling (DHM) tools have been successfully used for the assessment of design suitability at an earlier design phase. Now, there is a need to use these tools to identify mismatches between job demands and an individual's capabilities for a more diversified workforce. This is especially so, as manufacturing assembly activities become very important as these still require a significant physical involvement of workers. A more realistic 'design for all' approach based on the actual working capabilities of individuals is considered helpful, so that better, safer and healthier workplaces for all workers might be assured. This can possibly lead to safer and more productive working environments where organizations gain benefits in terms of workforce satisfaction, improvement in productivity and quality of products.

**Keywords**-digital human modeling; computer-aided ergonomic; 'design for all' method; manufacturing assembly activity

## I. INTRODUCTION

Being ahead of market competitors is always an objective for any business management system where the provision of products with excellent quality at the cheapest cost is the key to success. All manufacturing companies face challenges in meeting the expectations of "doing more with less" so that manufacturing excellence of the production systems can be achieved leading to bottom line improvements. It is an established and well-proven fact that this excellence cannot be achieved without a skillful, competent, committed and satisfied workforce to ensure attainment of targets of high level market share by providing high quality products at the

lowest cost. Many times, manufacturing organizations demand high levels of capability from the workers across a range of aspects including physical, physiological, psychophysical and cognitive and this directly influences work performance. Moreover, workforce diversity in cultural background, age, gender, marital status, anthropometry etc. leads to further serious issues as people share different values, desires, needs, attitudes and work behaviors. These trends are very prominent in the countries that have multicultural societies, for example UK, US, Canada, and Australia. Poor management of this diversity can ultimately result in a mismatch between the capabilities of the workers and the demands of the job. It becomes challenging for planners, designers, managers and ergonomists to realistically understand the mismatches and devise appropriate solutions at some earlier design stage. Ergonomics has delivered valuable contributions on the subject of worker's capabilities and their relation to work. The simple approach of identification of issues, evaluation of the tasks associated with those issues and controlling exposure where task requirements exceed human capabilities; makes it easier to implement. However, there is still a need to investigate human capabilities and their variations so that organizations might have the best utilization of their human resource. A computer-aided ergonomics approach is considered useful for the evaluation of workstations, workplaces, products and processes and their relevance to inclusive design.

## II. COMPUTER-AIDED ERGONOMICS

The International Ergonomics Association (IEA) defines Ergonomics (or human factors) as "a scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theoretical principles, data and methods to design in order to optimize human well-being and overall system performance" [1]. Ergonomics is broadly divided into three main domains; physical, cognitive and organizational ergonomics which shows its multi-disciplinary nature. In this context computers are commonly used in the creation and modification of designs as they assist designers through graphical visualizations of the early design stages. The assessment of human performance, prediction of risk elements

and non-productive scenarios through computer-aided ergonomics tools is quite common [2]. Nowadays, evaluation of ergonomic aspects of any design by using computer-aided tools and techniques is an established methodology [3]. These tools have the ability to develop a three-dimensional model of products, equipment or workplaces, a three-dimensional human model for design assessment purposes and an interactive user interface with evaluation techniques [4]. SAMMIE (System for Aiding Man-Machine Integration Evaluation) is considered to be the earliest digital human modeling (DHM) tool that can evaluate human model fitness in a workplace by using different criteria like reach, fit, move, different body postures and comfort with the help of joint angles. How this tool can be used in an ergonomic analysis, is shown in Fig 1.

Realistic representation of a human model in any digital human modeling tool is a key element for achieving best design evaluations. However, it has always been a challenge for designers. Initially, 2D templates were used for the evaluation of any design which was upgraded with 3D-CAD systems, as any 2D template does not support the analysis of postures and comfort in a realistic way. On the other hand, accurate dimensionality of any human model is also a great challenge. To overcome all these difficulties and address the challenges, the RAMSIS human modeling system was introduced in 1980. It uses directly a real human for measurement purposes and sophisticated cameras are used to capture the three dimensional geometry of the human. The RAMSIS human model is processed at two levels; one is internal and other is external. The external level is the representation of body surfaces that contain 1200 anchor points and are attached to the internal model. The internal model is a human skeleton that

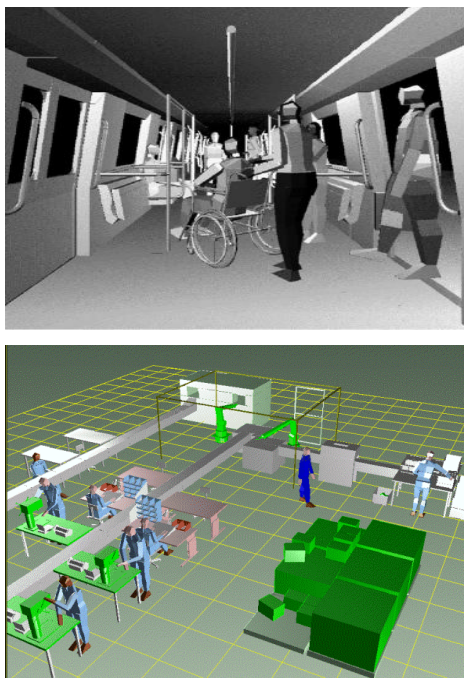


Figure 1. Use of human modeling system SAMMIE-CAD [3]

provides a base for kinematic characteristics and restricts the number of joints and their degrees of freedom [5]. Human Solutions GmbH provides many specialized products as digital human modeling systems against a variety of applications like RAMSIS Automotive, RAMSIS Industrial Vehicles, RAMSIS Bus and Truck, and RAMSIS Aircraft etc [6]. JACK is another digital human modeling tool and was developed at the University of Pennsylvania, USA, where researchers used a number of data sources so that the human model representation could be made more realistic. JACK provides options for bending and positioning of different parts because movements of different body parts are based on the principles of inverse kinematics [7]. It also has a task analysis toolkit that can be used to perform a variety of ergonomic assessments like lifting analysis, fatigue and estimated time for recovery, low back analysis and predetermined times etc. [8]. It is widely used in industrial organizations and many success stories have been described in the literature. In one case, it has been successfully used to perform ergonomic analysis for a space station design, where 640 different activities were analyzed for different requirements like body posture, reach, space requirement and viewing an object. Results show that only nine out of four thousand requirements are not found suitable for JACK analysis. These facts show importance of its use in such typical application where all analyses were performed according to NASA zero gravity specifications [9]. Fig. 2 shows natural body position of a 5<sup>th</sup> percentile Japanese female and a 95<sup>th</sup> percentile American male according to the NASA specification of zero gravity and a female astronaut performing an activity which is one of the 640 activities analyzed by using JACK. Moreover, its successful use in the evaluation of assembly working positions and sequences were carried out by analyzing workload, reach and visual constraints [10].

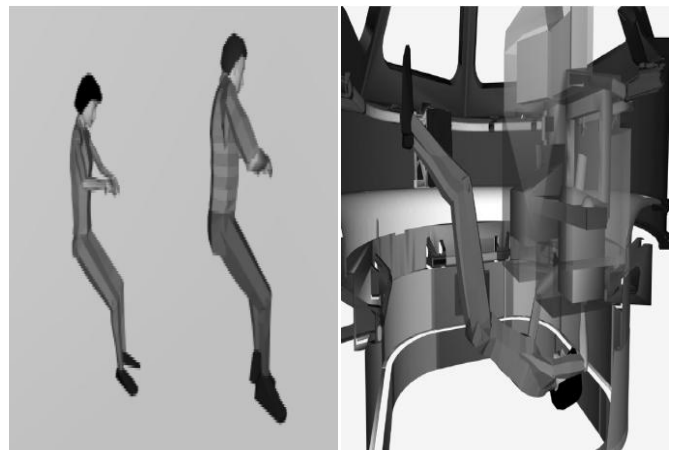


Figure 2. Use of digital human modeling system JACK [9]

The above discussion reveals that the use of digital human modeling tools is equally productive for a wide range of

applications. However, there is still a need to address many issues so that a more realistic representation of any human model can be ensured. Previously, the focus of research efforts was to address issues like variety of sizes, body shapes etc. but now research is on the way to accommodate the human diversity in capabilities and behaviors so that more realistic and logical investigations can be made. To address all these issues, a more realistic digital human modeling approach is described below.

### III. A DIGITAL HUMAN MODELING, ‘DESIGN FOR ALL’ APPROACH

An approach used to address the design needs of a broader range of the population is called a ‘design for all’ or ‘inclusive design’ approach. The objective of this approach is to understand and address the design requirements at some pre-design phase so that any product, service, environment, tool or equipment can be designed in such a way that it could be used by a broad range of the population. The ‘Design for all’ approach takes a deep insight of human capabilities and disabilities; and provides information about why some people are excluded from a design and how they might be accommodated [11]. To support this method, an effort was made to integrate a 100 people database called HADRIAN (Human Anthropometric Data Requirements Investigation and Analysis) consisting of more realistic information about sizes, shapes, capabilities and behaviors with a digital human modeling tool SAMMIE (System for Aiding Man Machine Interaction Evaluation); where a task analysis tool was also developed to support the designers. The HADRIAN database consists of people belonging to different age groups, backgrounds, levels and types of disabilities that directly influence their task performing capabilities. The objective was to support designers with highly relevant and useful data about a broad range of the population, and to provide them with an easy way to use that data so that more realistic and acceptable design decisions can be made at some earlier design stage [12].

Previously, it has been used for some simple applications like the use of ATM for wheelchair users and wheelchair access to trains and vehicles, as shown in Figure 1. Subsequently it was decided to enrich the database with some task-related capability data that is applicable to design investigations. The primary objective was to help and facilitate older and disabled people so that they could perform kitchen and transport based activities independently. For that purpose, photographs and videos of number of people performing those tasks were recorded and then postural coding was carried out to enter the data into an analysis system [12]. Fig 3 shows how the data in the form of videos and photographs was recorded, whereas Fig 4 demonstrates the use of task specific data in the modeling system where one can see the usefulness of this strategy



Figure 3. Recording individual's capabilities and behaviors performing kitchen-based tasks.



Figure 4. Adoption of the postures influenced by the behavioral coding recorded for individuals

This HADRIAN representation of 100 individuals was an effort to represent a maximum proportion of the population by providing extremely relevant and invaluable information about their anthropometry, physical capabilities and task behaviors. Fig 5 shows how this database presents an individual's data set during the design process where a designer can have a deep insight into individual capabilities before reaching a design decision. It also clarifies how a task is described in the task analysis tool for any design analysis.



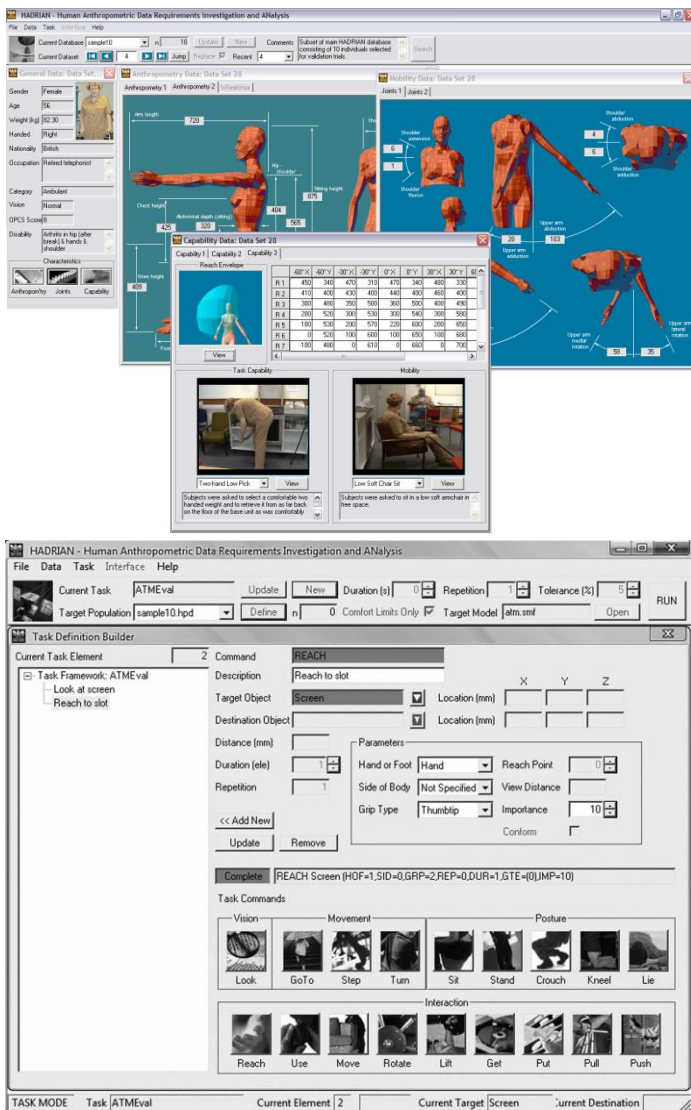


Figure 5. Screen shot of HADRIAN individual's data presentation and task analysis system [14]

of their type and severity of disability. People with joint mobility constraints usually face problems where they need to physically interact with products or equipments. The objective of this case study was to validate whether the human modeling system could provide us with the necessary information that could be used in the design process where the design of any product can be modified in such a way that it might be easily used by people with joint mobility constraints; these mobility constraints can be either due to age, some accident or stroke etc. It is obvious, when joint constraints of such participants (users) are applied in SAMMIE and HADRIAN, the human modeling system will indicate difficulty in approaching interaction points like controls, coin slots etc. Figure 6 shows that a wheelchair user with limitations in joint mobility will adopt a sideways strategy to reach all interaction points. However, users also face a poor viewing angle to the screen. From this case study, it was found that users with limited joint mobility will find it difficult to reach interaction points in a face-on approach, whereas an angled (sideways) approach would make it possible for them to reach all points. Moreover, users would feel difficulty in reading all necessary information displayed on the screen because of an improper viewing angle. Virtual analysis performed in SAMMIE and HADRIAN systems, provided useful design recommendations that would improve a ticket machine design; a design that is equally friendly for older and disabled users. DLR management will consider these recommendations during the refurbishment of the Greenwich DLR station.

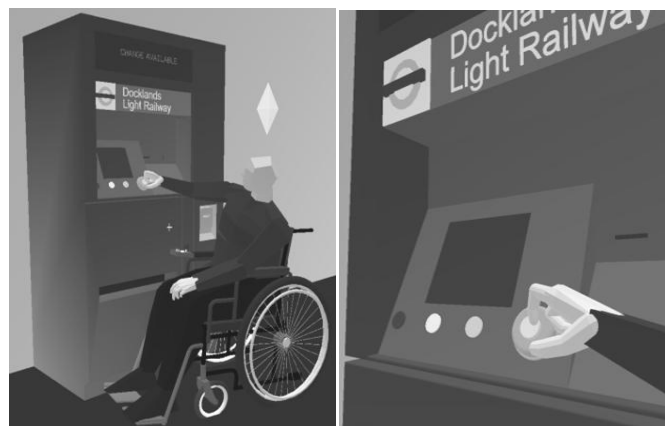


Figure 6. Ticket machine analysis with a participant has limited joint mobility

However, there is still a need to do more work on the realistic representation of human in any human modeling tool, so that more reliable and accurate design investigations can be made. This objective cannot be achieved until and unless designers can model human capabilities, coping strategies and behaviors within the modeling systems. The next section discusses a validation case study recently conducted at the Greenwich Dockland Light Railway station.

#### IV HADRIAN VALIDATION CASE STUDY

This case study describes how the HADRIAN human modeling system can be used to address the design needs of users with different capabilities, where anthropometric and joint mobility data with work performing strategies is used to access whether or not an individual or group of people is able to perform a task. In the current case study, the analysis of a ticket machine used by the Docklands Light Railway (DLR) is carried out by using the human modeling system. The actual participants were matched to HADRIAN sample on the basis

#### V INCLUSIVE DESIGN IN MANUFACTURING INDUSTRY

Modern manufacturing systems demand the best work performance from workers and the workforce needs to perform under tight production schedules and quality constraints. Keeping in view the current economic crisis and global workforce challenges, organizations will need to adopt new strategies to counter 21<sup>st</sup> century challenges for their survival in highly competitive and customer focused markets. Leading and sustainable manufacturing organizations have to focus on their human resources, instead of just their technical resources. Creating an uninterrupted, healthy, safe and

productive environment where workers feel themselves valued, will be a key element for success.

Moreover, retention of skilled and experienced workforce is not simply retaining a person but it is more about the use of experience, skill, knowledge and relationships. If any organization has lost experienced workers, regaining those lost skills, knowledge and relationships require resources in the form of money and time [15]. Like many other organizations, manufacturing organizations also need to manage a diversified workforce where workers belong to different age groups, backgrounds, anthropometry and especially with different working capabilities and behaviors. So, there is a need to address these issues so that future manufacturing organizations can get maximum benefit from their diversified workforce. As mentioned above, conventional digital human modeling tools just address basic issues of human diversity like body sizes, shapes etc. However, currently the

Workforce population is ageing and communities are becoming cross-cultural, and it becomes essential to realistically understand these complexities and devise appropriate strategies to address them.

To address all these issues, the 'design for all' approach is again considered useful as it aims to accommodate a maximum proportion of the population during a design process. Current ongoing research is focusing on the use of HADRIAN digital human modeling method into industrial environments, especially manufacturing assembly activities where majority of the activities are completed manually. A pilot study has already been completed and preparations made for a full-scale study. Assembly activities have been recorded in the form of photographs and videos so that the actual working capabilities, strategies and behaviors of a variety of workers can be used input to the human modeling task analysis system. Assembly tasks are being divided into their fundamental components and coding for the adopted postures is being carried out for the use of actual data in HADRIAN. Figure 7 shows two snapshots from a video captured at a furniture manufacturing company, where people from different age groups, skills, shapes and sizes have been selected and their task performing strategies captured.



Figure 7. Recording individual's capabilities and behaviors performing manual assembly tasks

## CONCLUSIONS

Successful use of digital human modeling (DHM) tools is evident in the literature. However, there is still a need to address a number of issues that need the attention of researchers so that a more realistic representation of human diversity in capabilities, behaviors and coping strategies might be addressed. The HADRIAN, 'design for all' approach tries to accommodate the design needs of the maximum proportion of the population in a digital human modeling environment. A task analysis tool provides feedback on whether or not an individual can perform a specified task and provides information on why individuals are designed out. Manual assembly activities cover a major part of manufacturing work where majority of the activities acquire human involvement. Current research is focused on the realistic representation of human capabilities and behaviors in an inclusive design human modeling system, so that today's manufacturing organizations can accommodate the design needs of a diversified workforce. This research will potentially give benefit to the manufacturing organizations in the form of the retention of a skilled workforce, improvement in productivity and quality and workforce satisfaction allowing organizations to take advantage of workforce diversity.

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