This paper covers the main reasons for proactive ergonomics and the use of Digital Human Model tools (DHM tools or manikin tools) in the automotive manufacturing industry. The tools are applied in the design, modification, visualization and analysis of human workplace layouts and/or product interactions. The paper explains why the manikin is used during the manufacturing development process, from the earliest phase to start of production. Setting early ergonomic requirements aims at several goals simultaneously: preventing work related musculoskeletal disorders, creating good assembly premises, attaining good quality work and keeping costs as low as possible. The paper also mentions important prerequisites for a successful use of DHM tools. Furthermore, the paper stresses the needs for methods able to assess motions and cost/benefit calculations connected to results from ergonomics analysis.

virtual ergonomics, manikins, frontloading, proactive ergonomics

1 INTRODUCTION AND OBJECTIVE

DHM tools, such as 3DSSPP (Chaffin, 1969), Jack (Badler, 1993) and Ramsis (Seidl, 1997), have been introduced in industry to facilitate a faster and more cost efficient design process. The tools are applied in the design, modification, visualization and analysis of human workplace layouts and/or product interactions. It is imperative that clear and very well defined ergonomic requirements are set at an early stage in the manufacturing engineering process soon after the start of a new project (Koufteros et al., 2001). The later this is done, the more difficult it will be to influence and change parameters that badly affect the work conditions. Changes are increasingly difficult to make the closer it is to the start of production and become much more costly. This paper is not a formal research paper, but gives a course description of why and how DHM tools and proactive ergonomics are used at Volvo Car Corporation in order to find problems and their solutions in an early project stage rather than finding them too late (at start of production or even later).

1.1 Musculoskeletal disorders

The Swedish Work Environment Authority has made work environment surveys in Sweden since 1989. During the period 2004-2005 some 370,000 employees had suffered discomforts from strenuous work postures (Arbetsmiljöverket, 2005). Upwards of 1,000 new musculoskeletal disorders (MSDs) were reported in 2005 as work injuries. Furthermore, the Work Environment Surveys show assembly workers to be a vulnerable
group. Male assembly workers, and still more so vehicle assemblers show large proportions replying that they have had work-related disorders due to strenuous work postures (14%), heavy manual handling (12%) and short, repetitive work operations (9%) in the year preceding the interview.

More than 600 million working days are lost due to work related ill health each year in the European Union. Available cost estimates of MSDs put the cost at between 0.5% and 2% of GNP (European Agency for Safety and Health at Work, 2000). MSDs are commonly reported work related health problem by European workers. 30% (44 million European workers) complain of backache; 17% complain of muscular pains in their arms or legs; 45% report working in painful or tiring positions; 33% are required to handle heavy loads in their work (Paoli, 1999).

The only routinely collected national source of information about occupational injuries and illnesses of U.S. workers is the Annual Survey of Occupational Injuries and Illnesses conducted by the Bureau of Labor Statistics (BLS) of the U.S. Department of Labor. For cases involving days away from work, BLS reports that in 2001, 522,528 cases (appr. 34%) were the result of overexertion or repetitive motion (BLS, 2003). The precise cost of occupational musculoskeletal disorders is not known. Estimates vary depending on the method used. A conservative estimate published by NIOSH is $13 billion annually (NIOSH, 1996). Others have estimated the cost at $20 billion annually (AFL-CIO, 1997). Regardless of the estimate used, the problem is large both in health and economic terms.

All these figures show how widespread MSDs are today, and justify the effort to design production systems to fit the workers. A sound and healthy working environment is not just something that the law demands, it is also profitable. It enhances employees’ well-being, satisfaction and performance and results in lower costs for sick-leave and less employee churn (Toomingas et al., 2005).

1.2 Relationship between ergonomics and manufacturing quality - productivity

Several studies have identified a relationship between ergonomically problematic work tasks and quality deficiencies to the extent that around 30-50% of all quality remarks are related to or directly due to ergonomic problems (Axelsson, 1994; Axelsson, 1995; Eklund, 1995; Hallberg, 1995; Sandström and Svensson, 1996; Eklund, 1997; Moestam Ahlström, 2002). A poor work environment in companies results in a number of consequences such as sick leave, rehabilitation, staff turnover, replacement costs, production loss and quality losses. Later research has shown that costs of poor ergonomics can indeed be very high. In the Ford Motor Company, North America, it was found that poor ergonomics resulted in direct yearly costs of $26 million before sick leave compensation and medical treatment. If these were included, the costs were estimated to be $47 million annually (Stephens, 1999). In addition there were indirect replacement costs to at least $141 million per year. At Jaguar- and Land Rover’s production plant in England it was found that each occupationally injured employee costs the company $50,000 per year (Price, 2004). Estimates made at Volvo Car Corporation showed that a poor ergonomic work operation on average amounted to an increased annually cost of $170,000 (Falck, 2005).
1.3 Reduce time to market

Time to market is a critical success factor in today’s business environment. The challenge is to reduce the development cycle without sacrificing the performance and quality of the products (Cohen et al., 1996). With the short-lived products of today’s competitive global markets most of the engineering has to be done before the start of the production and simultaneous with product development (simultaneous engineering) (Rauglas, 1998).

1.4 Computer-aided engineering / Computer-aided design

Any use of computer software to solve engineering problems is called computer-aided engineering (CAE), and has become one of the most important tools for simultaneous engineering. With the improvement of graphics displays, engineering workstations, and graphics standards, CAE has come to mean the computer solution of engineering problems with the assistance of interactive computer graphics (Myklebust, 2001). Computer-aided design (CAD) refers to the use of computers in converting the initial idea for a product into a detailed engineering design. The evolution of a design typically involves the creation of geometric models of the product, which can be manipulated, analyzed, and refined. In CAD, computer models and graphics replace the sketches and engineering drawings traditionally used to visualize products and communicate design information (Preston White and Richards, 2002).

1.5 Digital human modelling tools

In line with other engineering software development DHM tools have moved from a 2D to a 3D world. Fast, high quality computer graphics now allow us to render lifelike images (manikins) of people performing multitude tasks within various computer aided design programs. Thus it now is possible to position and move manikins to predict the performance capabilities of designated groups of people within a computer rendered environment (Chaffin, 2001). Many MSDs can be prevented using ergonomic interventions - to modify work and workplaces based on assessment of risk factors (European Agency for Safety and Health at Work, 2000). The manikins are used to visualize/analyze hand and tool accessibility, reach ability and achieved body posture and field of view (Figure 1).

1.6 Holistic view for good ergonomic result

Many years of experience have shown that the choice of styling and design solutions, materials, manufacturing engineering and manufacturing concepts is crucial for the final ergonomics outcome in the plant (Munck-Ulfsfält, 1997) (Figure 2). Factors that can be influenced in terms of the individual in the actual work place are responsibility, work technique and consideration/respect: the operator should work in a good way, that is, use the required facilities (i.e. lifting equipment), show consideration to the members of the work team and apply a careful and well adapted work technique. The design of the work place to a high degree decides what work postures can be taken, what work movements will be predominant and what work load the individual will be exposed to, such as weights, forces and level of exercise. The work organization decides through the time factor how long and often various work tasks will be performed as well as the degree of variety of the work contents. The degree of influence decides to what extent the operator he-/herself can model the work by deciding how it should be carried out.
The manufacturing process design is also of vital importance for the autonomy of the worker (e.g. level of automation and buffer sizes). For those reasons it is imperative that clear and very well defined ergonomic requirements are set already at an early stage in the manufacturing engineering process soon after the start of a new project (Figure 3).

Figure 1: The assembly task of a parking aid unit (Volvo S80) is conducted in a virtual environment to assess accessibility and hand/tool clearance, reach ability, field of view and working posture. The smallest manikin (female 5th percentile; left column) and the largest manikin (male 95th percentile) are used.

Figure 2. There are many interrelated factors that influence production ergonomics, such as technical factors, organizational factors and human factors (Munck-Ulfsfält, 1997).

The later this is done, the more difficult it will be to influence and change the above factors since many decisions are made very early. Changes are increasingly difficult to make the closer it is to the start of production and become much more costly. What cannot be solved during a product change must instead be compensated for (as far as possible) by a very well designed work place and an adapted work organization offering work rotation to other tasks, giving bodily variation (Falck, 2004).

1.7 The purpose of proactive ergonomics and virtual ergonomics
The activities around proactive ergonomics and virtual ergonomics are all initiated early in a project. The purpose with the activities is to find assembly solutions with no
ergonomics problems – no blind assemblies (free line of sight), no harmful postures, no entering of car bodies, no "third-hand-solutions", sufficient clearances for hands/arms/tools, no harmful liftings, and no time-critical assemblies.

Figure 3. Principle description of ergonomics influence during the product development process.

1.8 Prerequisites for a successful use of virtual ergonomics

The use of DHM tools is based upon 3D models. If there are no 3D models describing products and process equipments the basic idea with DHM tools more or less vanishes. Furthermore, a well organized and structured database containing all 3D models is an indispensible – the database must support describing different variants as well as a "chronological added value history" for all these variants. Today such a database is referred to as a PLM-system (Product Lifecycle Management-system). A thorough knowledge in ergonomics is necessary to be able to interpret the ergonomics simulations. This emphasizes the need for a cross-functional cooperation between different disciplines such as: simulation engineers, ergonomists, designers, and manufacturing engineers; with the DHM tool as connecting tool.

2 CONCLUSION

Swedish manufacturing industry has been subject to powerful changes during the last ten years due to the market globalization. A large number of international mergers have created a decreasing number of companies with increased competitiveness. To keep and gain market shares it is increasingly important to shorten the time to market with new functional concepts with high enough news value without failing to meet market demands of high quality, reasonable price and short delivery times. Simulation is seen as a mean to meet these demands (Rauglas, 1998; Chaffin, 2001). Flexible simulation tools and a smooth communication, within the company as well as along the chain of suppliers, become increasingly vital for the pre production engineering of a car manufacturer. Today virtual ergonomics (and simulation in general) is a technology that is commonly applied at Volvo Car Corporation and has come to stay. However, Volvo Car Corporation has made large investments in simulation tools for production engineering and the tools require substantial investments in time and money. Furthermore,
accurate methods able to assess motions are lacking, as well as cost/benefit calculations connected to results from an ergonomics analysis. In order to successfully implement the use of a DHM tool in an organization it is vital to develop a DHM tool working process. Such a process improves both the quality of necessary input-data-contents and output/result presentation after fulfilled simulation.

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4 REFERENCES


BLS. (2003). Number of nonfatal occupational injuries and illnesses with days away from work involving musculoskeletal disorders by selected worker and case characteristics, 2001. U.S. Department of Labor (Published in March 2003).


