Applicability of Human Simulation for Enhancing Operations of Dismounted Soldiers

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ABSTRACT

Current policies of the Alliance require the constant development and acquisition of new technologies and equipment to support the individual soldier. Applying different types of modeling and simulation (M&S) for the design of equipment has been advantageous in the past. This has gained importance ever since the dismounted soldier is considered as a system, rather than a set of single components. M&S of human factors facilitated a comprehensive analysis of different components and their interaction with each other at early design phases. Constructive simulation, e.g., allows the identification and estimation of shortcomings and capabilities of new technologies without the need for cost-intensive hardware prototypes or demonstrators. An optimization of mission procedures becomes feasible with human performance modeling.

This paper addresses relevant issues and some lessons learned in this field. It presents results and lessons learned from applying a mix of constructive, virtual, and live simulation for the design of future soldier equipment. A model of a (kinetic) MOUT mission (Military Operations in Urban Terrain) serves as a basis for a procedural simulation model, including simulation of mission processes, sequences and human performance. Design of personal equipment was investigated by today's digital anthropometric human models. The focus in this case was on the validity of commercial models for typical dismounted soldier actions. It is planned to analyze the application of virtual simulation for more detailed analyses, esp. the applicability of commercial gaming technology, will be investigated. This will also include virtual entities, which were controlled by a simple artificial intelligence. In this connection, serious gaming has potential for applications in training social and cultural factors at a low operational level.

1.0 INTRODUCTION

Modeling and simulation has frequently been used for various military applications. This covers domains like education and training of military personnel, design of military equipment and platforms, and optimization of operational organizations and processes. Nowadays, there are many modeling and simulation tools available, which are applicable and offer functionality for special applications. However, the applicability of these tools is limited when using them beyond their special application. It is important to be aware of these limitations. Therefore, proof-of-concept and validation studies are required.

In general, "*simulation is the process of designing a model of a real or imagined system and conducting experiments with that model. The purpose of simulation experiments is to understand the behavior of the system or evaluate strategies for the operation of the system*." [1]. Because most problems in the real world are far too complex for a comprehensive model with all the facets, the simulation simplifies the real world and is always limited to relevant aspects.

In military terminology, simulation can be divided into Constructive, Virtual and Live-simulation [2]. For Constructive Simulation the technical system and the human operator are both simulated. This facilitates

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Current policies of the Alliance require the constant development and acquisition of new technologies and equipment to support the individual soldier. Applying different types of modeling and simulation (M&S) for the design of equipment has been advantageous in the past. This has gained importance ever since the dismounted soldier is considered as a system, rather than a set of single components. M&S of human factors facilitated a comprehensive analysis of different components and their interaction with each other at early design phases. Constructive simulation, e.g., allows the identification and estimation of shortcomings and capabilities of new technologies without the need for cost-intensive hardware prototypes or demonstrators. An optimization of mission procedures becomes feasible with human performance modeling. This paper addresses relevant issues and some lessons learned in this field. It presents results and lessons learned from applying a mix of constructive, virtual, and live simulation for the design of future soldier equipment. A model of a (kinetic) MOUT mission (Military Operations in Urban Terrain) serves as a basis for a procedural simulation model, including simulation of mission processes, sequences and human performance. Design of personal equipment was investigated by todays digital anthropometric human models. The focus in this case was on the validity of commercial models for typical dismounted soldier actions. It is planned to analyze the application of virtual simulation for more detailed analyses, esp. the applicability of commercial gaming technology, will be investigated. This will also include virtual entities, which were controlled by a simple artificial intelligence. In this connection, serious gaming has potential for applications in training social and cultural factors at a low operational level.

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large flexibility and variability within the system design process. Large adjustments in the construction design are possible with minimum efforts. But simulating the human operator is always critical because of the large variance of human characteristics and behaviors. On the other hand, Virtual Simulation involves real humans operating simulated technical systems. This requires additional efforts. It also reduces flexibility and variability of system design or process optimization, but it enhances face-validity and validity of the results. Finally, Live-Simulation includes real operators and real technical systems. It is closest to reality, but it offers only very few flexibility. Moreover, Live-Simulation requires often technical prototypes, which can be used for field-experiments. It is costly in terms of labor and time.

In the approach described in this paper, a mix of Constructive, Virtual, and Live simulation is used to analyze selected chapters of future soldier operations and personal equipment. A model of a (kinetic) MOUT operation (*Military Operations in Urban Terrain*) serves as a basis for a procedural simulation model, including simulation of operation processes, sequences and human performance. The results required more detailed analysis of the design of personal equipment. This was investigated by applying today's anthropometric Digital Human Models (DHMs).

The German Soldier Modernization Program (SMP) served as practical background for the proof-of-concept study. The SMP subsumes many new components, so that a comprehensive system's approach is required [3]. The focus is the general functionality and validity of simulation packages for typical dismounted soldier actions. Of course, the results presented in the following are not universally valid, but they give a good understanding of possibilities and limits of today's simulation tools. They also show the need for a more comprehensive simulation model of the human operator.

2.0 CONSTRUCTIVE SIMULATION FOR PROCEDURE OPTIMIZATION

Most products for task analysis and process planning were designed for industrial applications like industrial process planning during manufacturing and maintenance. Several of them have been applied successfully for military applications [4, 5]. In this approach we used them to model a MOUT operation of a squad of soldiers. The approach consisted of a data capturing phase, in which field-trials at a German MOUT training facility were observed, a subsequent data-processing including analysis of video and audio data, and a modeling phase, which resulted into a descriptive model of procedures, tasks, and parameters. The model was then transferred into a simulation model which allowed estimating effects of e.g. additional weight by a ballistic vest on mobility and efficiency [6].

2.1 Data Capture

The first phase, i.e. data capture, took place during a military exercise at a special MOUT training facility in Germany. In total, 16 soldiers participated in the exercise during a period of two weeks. The soldiers were equipped with system components of the SMP. It included ballistic protection vests, assault riffles, protecting glasses, UHF-radios and PDA computers for enhanced situational awareness. The relevant military tasks were approaching, clearing, and securing a single building. This included actions like overcoming obstacles, intrusion into a two-story building, fighting from room to room, and fighting from floor to floor. Figure 1 shows a snapshot of the intrusion into a building through the second floor. In each single exercise two groups of four soldiers each participated. Each group was led by a sergeant. The actions and their sub-tasks were exercised and repeated several times for each group. The sequence of the single tasks and procedures were pre-determined, with little or no variance. This was caused by the characteristics of military training. As expected, processing times varied vastly and were reduced during training.

Figure 1: Snapshot from the MOUT-operation exercise which served as basis for the model.

All activities were captured digitally from three different perspectives. The three video streams were later video-processed and analyzed. Additionally, the active group members carried digital voice recorders to capture audio stream. These data allowed a comprehensive analysis of the actions during the MOUT exercise.

2.1.1 Action 1: Overcoming a First Obstacle

This phase included different tasks and activities during the approach to the target building. The phase was initiated by delivering a fog grenade, overcoming a barbed-wire obstacle and arriving at a secure place next to the building. It also included commands for approaching, subsequent actions, and final confirmation messages. The main goal was to approach the building as fast as possible and to secure the group from potential enemy fire. Many repetitions of the tasks were executed so that sufficient data for a subsequent modeling is available.

2.1.2 Action 2: Entering the Building

In the following, the group entered the building through a window in the second floor. A single soldier was left behind in order to secure the entrance against potential enemy fire. This action includes primarily directed communication (commands of the sergeant, confirmation messages of soldiers) and various sequential activities. Activities, e.g. climbing a ladder, were carried out by each of the different team members. This required different amounts of time and large variances were observed. A reason for this is that climbing the latter wearing full ballistic protection requires high energetic workload.

2.1.3 Action 3: Fight from Room to Room

Each soldier was highly engaged during fight from room to room. These actions required high energetic workload and happened with high time pressure. Before exiting a room, a single soldier was left behind in order to secure the room. Consequently, troop size was reduced. Because of the high temporal demands communication was limited to simple one-word commands and short confirmations. Mobility is considered to be essential.

2.1.4 Action 4: Fight from Floor to Floor

The fight from floor to floor also included doorways and staircases. They were entered and secured slightly differently, thus requiring more time and different messages.

2.2 Data Processing

The subsequent, offline data processing is primarily done by commercial video processing software. It includes the sequencing of tasks as well as a detailed description and determining processing times for each single task. Data processing is intensive in terms of labor and time. Several actions and tasks were carried out in parallel, so that it is important to note the correct timeline. The data processing results into a sequence of actions and task performance, and a description of the duration of each task and sub-task. Because the operations were repeated several times it was possible to determine and include variance in the model.

2.3 Descriptive Modeling

The descriptive modeling phase transfers the sequence and characteristics of the tasks described before and transferred them into a first descriptive model. The notation of the model is based on the K3-method (coordination, cooperation, communication) and allows a graphical description of industrial processes. In general, K3 is based on the Unified Modeling Language [7]. The K3-method was found to be especially suitable for cooperative, slightly-structured working processes. It has been successfully used for applications in industrial sciences. The visualization of cooperative work and task assignment enhances a general understanding of interrelationships and operation activities [8]. K3 includes graphical elements for describing activities, blogs (i.e. groups of activities), information, and tools, and their connectors. The connectors used for K3 are: control, decision, information or objects, synchronization and synchronized cooperation.

During the modeling phase it was discovered that some additional features were required [9]. The according functionalities were added to the notation, so that special communication connectors with different colors and styles represent the various communication media. The model itself was used to identify core problems, e.g., wrong procedures during mission execution, inappropriate task assignment between team members, and time lags in critical operation phases. Because mobility and effectiveness were of high importance, quantitative time assessments were carried out and a timeline was added to the model. In our case, each column represents a single person which is either active or non-active and carries out different tasks or actions. By including mean and variance of time a more comprehensive analysis became possible.

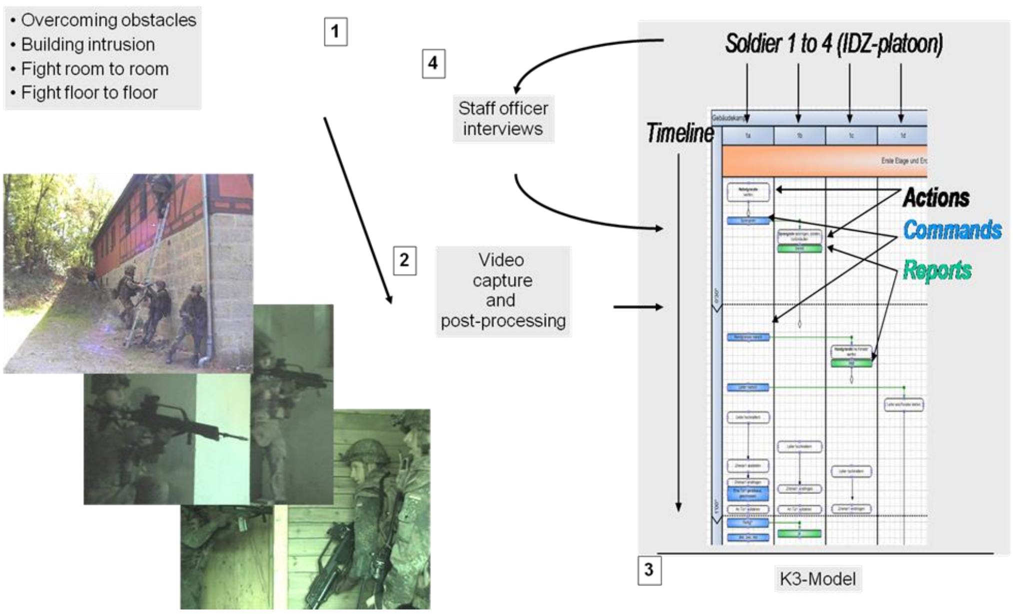

Figure 2: Process of modeling and subsequent optimization by SME-interviews [6].

By integrating the four stages into a full operation model, a more comprehensive analysis became possible. However, describing tasks and actions of 16 soldiers led the notation to its limits. Therefore, the full operation was structured sequentially. The model was finally verified by interviews with special military Subject Matter Experts (SME).

2.4 Application of the Simulation Model

The descriptive model was subsequently transferred into a simulation model. For this, the MicroSaint™ Sharp simulation package was used [10]. It s a multi-purpose, discrete-event simulation tool that allows the modeling and simulation of processes and human performance. MicroSaint™ Sharp visualizes activities and actions as a flow chart. It can be used to model, modify and optimize processes in different applications by carrying out "what if"-analyses. The simulation model itself is divided into a discrete and a continuous basic component part. The discrete component describes the baseline network, which is characterized by special attributes of the processes. The continuous component consists of a mathematical description of the according state variables. The ongoing processes define the knots of the network, while the edges represent the connection between the processes. Further elements of the network address available resources and relevant system states.

In our case, the soldier serves as a resource, the military action describes the process, and the connections are defined by the sequence of actions. Because of a similar representation with the K3-model and the MicroSaint™ Sharp model, the implementation is simple. However, several additional activities, e.g. stochastic elements and repetitions for malfunctions, have to be added. For the parameterization of the continuous elements the results from the data processing served as input. This allowed a stochastic modelling of state variables and transfer functions.

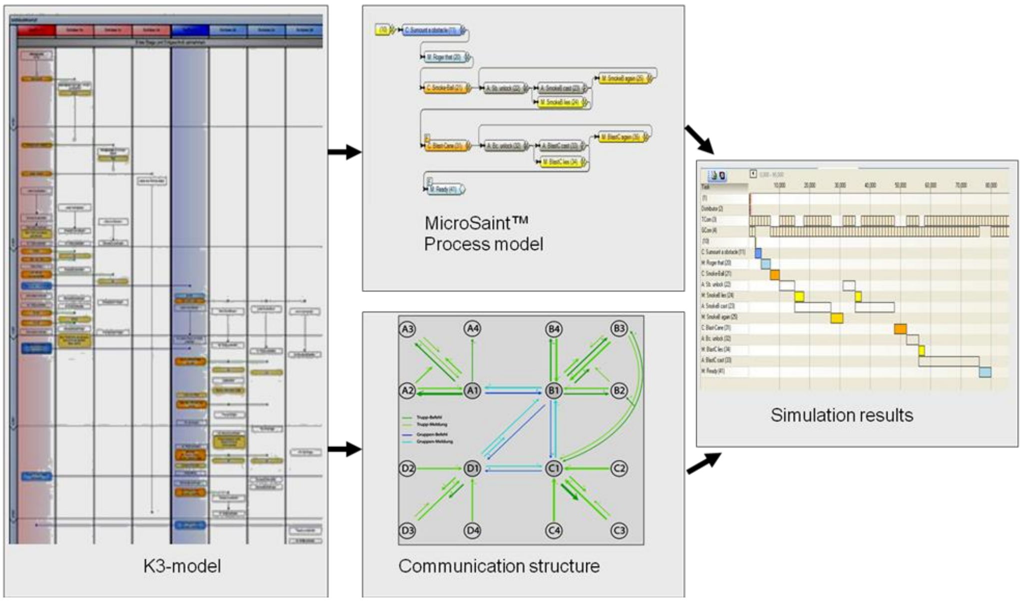

Figure 3: Transfer of the K3-Model into a MicroSaint™ process model and simulation results [6].

The simulation was used to estimate the effect of ballistic protection (weight: ca. 25 kg) on mobility. The analysis was carried out for each phase of the operation. Because of the complexity of the operation (some actions took place in parallel, some did not) and the involvement of multiple soldiers, the results were not trivial. In fact, simulation revealed that the approaches to the building did not differ significantly from each other. Entering the building required significantly more time with a ballistic vest. On an average, this phase took on the average 22% longer. Fights from room to room and securing each room also required significantly more time (15% on the average longer action times). Similar results were found for fighting from floor to floor. Process time for this action was 25% on the average longer.

The important result of the simulation was that, although single actions took between 15 and 25% longer, the total operation time was not significantly longer. In contrast to our expectation, the operation was only 6% longer with a ballistic protection than without. An explanation for this is that many actions take place in parallel or some actions have to wait for the completion of previous ones.

2.5 Conclusion

The K3-notation is found to be suitable for describing military urban team operations. Exercise data has been captured, analytically processed and transferred into a descriptive model. The model includes task sequences, communication processes, and the according times. By subsequent interviews with military experts it is possible to evaluate and adjust the procedural model. This way, the K3 model becomes more detailed and serves as a basis for a later simulation. The K3 serves as a basis to identify shortcomings and generate possible solutions. The simulation revealed, that in contrast to significantly longer process times for each action, total operation time was only slightly larger with than without a ballistic vest. However, because this was only true for the special mission profile, the effect might be larger for mission profiles with higher physiological workload.

An insight analysis of critical elements revealed that especially the technical design of equipment had a vast effect on military effectiveness. Especially the weight of the ballistic vest and technical shortcomings of the design were found to impair military actions. Therefore, it was decided to analyze the use of modeling and simulation for the design of personal equipment.

3.0 DIGITAL HUMAN MODELS FOR EQUIPMENT DESIGN

For an ergonomic design of personal equipment the inclusion of human body dimensions has always been essential. Therefore, digital human models are available which model human body dimensions and human motion. Whereas first digital models were just simple CAD-versions of templates, today’s anthropometric models include complex algorithms for describing human body shape variability and basic human movement behavior. Today’s most common models are JACK, RAMSIS, Delmia Virtual Human 5 and SANTOS [11 ,12 ,13 ,14]. The background of JACK is primarily computer graphics and animation and this model is frequently used within computer-based training in Virtual Environment. Delmia Virtual Human 5 has a background in industrial sciences and workplace design. The main application area for RAMSIS is the automotive industry. SANTOS, finally, has been developed for special military applications and sponsored by the US-Army.

Because most of these DHMs come from vehicle or workplace design, it is important to investigate applicability and validity of the results before they are used for the design of military personal equipment. Such a validation study was carried out for ballistic protection. It is a critical element for the overall soldier performance.

3.1 Background and Motivation of the Study

The results of modeling human team performance described in the previous chapter show that ballistic protection and the interaction between different components of the personal equipment are critical factors for soldiers’ performance. However, a detailed analysis for the optimization of ballistic protection showed that in-depth analysis is required. The performance model was found to be insufficient for such an analysis, so Digital Human Models (DHMs) from another domain were applied. The key applications for

DHMs are ergonomic workplace and product design [15]. For these applications they are used as tools for analyzing sight, reach, posture, comfort, fatigue, etc. for a user population. The first DHMs were just simplified digitized versions of anthropometric percentile drawing templates. Modern DHMs are far more sophisticated. They use a complex methodology for describing and modeling human body shape, anthropometric dimensions, and their variability. Modeling of behavior and its variability is still a research topic, often relying on biomechanical models. It simulates simple goal-directed movements. More comprehensive human models, which also consider higher levels of human behavior such as tactical and strategic thinking, are still research topics and not totally integrated into design processes [16].

3.2 Experiments with New Personal Equipment

There are many potential conflicts with wrong designs of personal protection equipment. Protection equipment is always subject to high weight, which cannot be prevented. Therefore, it is important to fit it to the soldier needs and sizes. Unfortunately, most anthropometric models do not support contour measures, so that they cannot be applied for this. Instead, it is recommended to design sizes according to body contours from 3d surface anthropometric databases, such as CAESAR, WEAR or SizeGermany. They provide a vast set of body scans to optimize size and sizing scheme for individual protection equipment [17, 18, 19].

Important issues are conflicts between different parts of the individual protection equipment. A “traditional” conflict is the conflict between weapon visor, helmet, and posterior part of the ballistic vest. Another are range limitations because of the movement impairments caused by the ballistic vest. SME interviews revealed that these conflicts are most critical, so they were considered for the analysis.

3.3 Anthropometry and Motion Simulation

The analysis included a data capture section for capturing range and motions with different protection levels, a validation section with a cross-comparison of the real and simulated ranges and motions, and an analysis section with the identification of shortcomings and possibilities of today’s DHMs. The DHMs used for this study were RAMSIS and JACK. Application of SANTOS was not possible because there was just an early research version of this DHM available for the study.

3.3.1 Data Capture

Data capture took place at the German Infantryschool Hammelburg. 30 soldiers (age: AM=21 yrs, sd=2 yrs; 29 male, 1 female) volunteered to participate in the study. They were equipped with SMP-equipment and performed several motion experiments. Their movements during the experiments were recorded with an IR-optic, passive ART-Track Motion Capture System. It captured the 3d-positions of small, IR-reflecting markers with a measurement rate of 60 Hz. Results from prior studies showed that this system offers sufficient accuracy and precision for the study. Personnel were specially trained for anthropometric data acquisition and motion capture.

The experiment itself included the anthropometric measurement of the participants (49 body dimensions), marking of 9 special anatomic landmarks on their body with the markers for motion capturing, and performing several movement experiments for determining range and motion trajectories. The movements included determining maximum hand reach and range, changing between different shooting positions (standing, kneeling, prone), and operating a night vision system. Parts of these sequences were repeated for sport dress (light), uniform dress including C2-vest (medium), and with full ballistic protection (heavy). Figure 4 shows an example for operating a night vision system.

Figure 4: Example sequence of real motions.

The captured motion data was written into a database and processed afterwards. Processing included the implementation of diverse algorithms for semi-automatic marker assignment and subsequent error correction.

3.3.2 DHM Simulation

Anthropometry and motion were simulated with the two DHMs. At an initial step, the measured body dimensions served as input for the generation of different individual models. This step revealed that one of the models did not offer functionality to enter standardized anthropometric dimensions. Instead, it required the input of boundary measures for each body limb. With background information it was possible to calculate them. But this might introduce inaccuracies.

In the following step, maximum reach range was calculated and displayed. This is a standard-functionality and is possible with all DHMs. The calculated ranges are used for the comparison with the measured real ranges.

A final step subsumed the definition of tasks for the motion simulation. This step included a definition of targets for special anatomic landmarks and effectors for the starting, the intermediate, and the end posture. It was found that the simulation results did not match completely. Face validity of the simulated motions and postures during the movements showed that the automatic simulation was not sufficient. However, it was possible to generate realistic motion tracks, but this required additional efforts and background knowledge. A result is shown in figure 5. It was recommended that modeling realistic movements for applications other than car interior or workplace design requires additional research studies and implementations.

Figure 5: Simulated motion sequence.

3.3.3 Comparison and Analysis

Results from the simulation were finally compared with the real results. This allowed an identification of shortcomings and a first estimation of applicability of the DHMs for the design of personal protection equipment.

Anthropometry and Static Postures

As expected, the contour modeling of the DHMs was not realistic. Therefore, it is not possible to use a DHM for the design of clothing or a ballistic vest. A side-effect of this is that the simulated elbow-elbow breadth with ballistic vest is too small and a safety value has to be added. This is especially relevant for the design of transport vehicles for soldiers wearing ballistic protection. With regard to reach and range, the models facilitate fairly correct results. The maximum range corresponds with the comfortable and the maximum range of the real experiments. Results including breadth measures are often too small. This might result into too small side dimensions e.g. for seats in vehicles.

For relative simple postures, e.g. standing, which are similar to standard postures of the DHM, the results are considered to be realistic. However, more complex postures (e.g. kneeling or prone) require large manipulations of the model and extensive knowledge of the user. This is especially true, when additional effects of clothing or ballistic protection have to be considered. In this case, unrealistic postures are likely to occur.

Dynamics and Motion

In addition to anthropometry and static postures, validity of modeling the dynamic properties was analyzed. For this, the dynamic reach ranges between the DHMs and the real data were compared. It was found that inaccuracies between the three different clothing conditions are strongly dependent on the position and orientation of maximum reach. This is shown in figure 6. The maximum range of the DHM is larger than real ranges in the right and medium direction, while it is too small for the left direction. Especially downwards, differences up to 15 cm were observed. This limits the general applicability of DHM for equipment design.

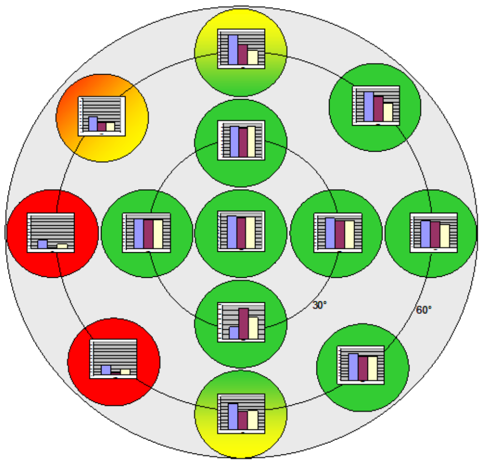

Figure 6: Comparison between real and simulated reaches. Red: Simulated > Real. Green: Simulated < Real reach [20].

With regard to motion simulation, the DHM are based on defining starting, intermediating, and ending postures. The intermediate postures were calculated by estimating optimal postures with the static posture models. A first analysis revealed that DHM are capable to simulate simple movements. For more complex movements, however, the results have to be critically analyzed. It often happens that movements and postures appear very unrealistic. As a result of the analysis it was concluded that motion simulation of DHMs is very limited, especially for individual human movements. More research is required in this field.

3.4 Results and Conclusion

Although modern anthropometric DHMs offer functionality for the design of personal equipment to a special degree, our results show these results differ from reality. This may be caused by the DHMs' background in car interior or workplace design and missing studies for the design of personal equipment. It requires modeling and simulation of individual motion and low-level movement behaviors.

Most of today's DHMs are not based on surface anthropometry or contour modeling. It is clear that their contours do not represent user populations. Therefore, they cannot be used to design e.g. protection vests or helmets. Instead, the application of special 3d-databases is recommended. But there are ongoing activities to overcome these shortcomings by linking DHMs to these databases. Modeling of body dimensions still requires the input of traditional anthropometric measures. This is not always the case with DHMs and may introduce additional inaccuracies at an early design step. In case of anthropometric measures, they have to characterize body characteristics accordingly (i.e. body height, body type, body proportions).

5.0 CONCLUSION AND OUTLOOK

This paper presents the results of our analysis for applying human modeling and simulation for the future equipment of infantry soldiers. It is shown that constructive simulation can be applied for describing, modeling and simulating MOUT operations. Constructive simulation facilitates an early estimation of effects of future equipment on soldier (team) performance. For more detailed analyses of special equipment and its interaction with other equipment, anthropometric digital human models were applied. They facilitate in-depth analyses of the design of future equipment. However, it was also found out that they have limited functionality for such application. Today's DHMs are limited with regard to accuracy and validity of the results. An uncritical use of them for the design of future equipment might lead to wrong designs and serious faults.

At this point there is no link between the two types of the model. First attempts have been made to integrate performance models and anthropometric DHMs, but they have not finished so far. It would be advantageous to integrate both models into a common software suite. In this case mission planning and design of personal equipment can be achieved within the same software and without the need for time-consuming transfer between two different pieces of software. This would be a step towards a comprehensive digital human model, which simulates different aspects of the human operator.

A general shortcoming is a missing simulation of higher behavior levels, e.g. for decision generation and decision making. Most DHMs act as templates with no intelligence and have to be operated manually. There are first approaches for controlling a virtual human model by artificial intelligence so that the model is able to identify objects and perform simple tasks. One example for an implementation of this procedure is Parameterized Action Representation (PAR) [21]. By this, DHMs can be used for populating virtual worlds. There are approaches within practicing and training communication and social skills. A popular case is a simulated checkpoint control [22]. A further recent installation simulates a highly-emotional situation during a military peace-keeping mission [23]. In this case the behavior of a crowd of people was simulated. Further installations work on using DHMs in order to train medical surgery personal [24, 25]. But these applications are still research topics, and have not made their way into operating systems yet. By integrating them into a common software with process models, performance models, and anthropometric models, it would become possible to create a more comprehensive model of the human which can be applied successfully for the optimization of mission and operation processes, designing personal equipment and training military personnel. Already including behavior modeling on various levels, as well as appearance, anthropometry, and biomechanics, is still a long way to go. It becomes even longer when incorporating emotional, psychological, cultural and sociological factors. The resulting anthropomorphic intelligent agents would then become a "real" virtual human for many other applications.

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