4 DIGITAL HUMAN MODELING FOR ERGONOMIC ANALYSIS OF REFRIGERATED CABINETS

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This paper presents a roadmap to evaluate ergonomic factors of refrigerated display units integrating virtual human models with virtual prototyping techniques in order to optimize the product development process and analyse alternative configurations of the product. Three users' categories (customers, operators and maintenance staff) with different roles, needs, and ways of interaction with the machinery have been considered. For each category, we defined a set of ergonomic simulation tasks using virtual manikins, procedures to be followed by the designer/ergonomics tester and results quantification. Ergonomic simulations have been carried out varying unit type, configuration, manikins' size and packed food.

Keywords: Digital Human Model, Virtual ergonomic simulation, Human factors in design, Refrigerated cabinets.

1. INTRODUCTION

During last decades, the use of Digital Human Models-DHM (or Virtual Human-VH) is attracting more and more interest in different industrial domains since the applications can be various and important. In fact, various companies are realizing that human element is not sufficiently considered during design, assembly, maintenance of products and processes.[1] Virtual humans can represent a valid tool to address ergonomic analysis and human factors related to both products and processes from the early phase of design process to the disposal,[1–3] i.e., during all their life-cycle, reducing product development times, reducing the need of physical prototypes,[9] lowering costs and improving quality.

Commercial frameworks with human models of different complexity are now available; some examples are Ramsis (www.human-solution.com), ManniquinPRO (www.nexgenergo.com), Jack (http://www.plm.automation.siemens.com) and Safework (http://www.safework.com/). They can be used to define complex scenes with virtual manikins and objects, simulate many tasks and evaluate ergonomics factors.

The application of DHM in ergonomics has been demonstrated by various research activities[1,4–8]; they refer to various industrial areas, but especially to automotive and aerospace. Even if current tools for human modeling offer a comprehensive and adequate set of functionalities, there is still the need to identify methodological approaches and guidelines for a correct and efficient use within the product development process in a specific industrial context.

In this paper, we focused the attention on virtual human modeling as a tool to integrate virtual prototyping and to carry out ergonomic analysis during the development process of refrigerated cabinets, commonly used in the supermarket to display packed food. Main goals are twofold: optimization of design process taking into ergonomic factors and different sizes of people and verify the potentiality and usefulness of ergonomics analysis using virtual human to predict and study the behavior of users' categories, which have different roles, needs, and ways of interaction with the product.

In the following, we first describe the context of interest, then the roadmap and finally ergonomic simulations and results obtained.

2. CONTEXT ANALYSIS

We first analyzed the industrial context considered in terms of: products (i.e., refrigerated cabinets), displayed packed foods, users' categories, ergonomic factors (e.g., visibility, reaching and grasping, comfort, etc.), and users' tasks.

Refrigerated display units have been studied in order to identify main product families and parts involved in the ergonomic analysis, such as unit overall dimensions, shelves position and sizes. Three main configurations can be considered:

- Traditional cabinets with horizontal refrigerated display units in two different versions: serve-over and self-service;
- Vertical and semi-vertical chiller or freezer units respectively to conserve and display fresh products and for optimum conservation of frozen products;
- Mixed configurations comprising both vertical and horizontal freezer units.

The units can display various types of packed food, fresh or frozen, characterized by different packages (rigid, semi-rigid, and soft), dimensions and weight. We mainly considered rigid or semi-rigid packed food, such as milk, yogurts or deli-packed, having generally weight less than 1 kg.

The design of such a machinery should accommodate the full range of users during its life cycle; i.e., from workers like fitters and maintenance men to the final users. We considered 3 main categories: customers, supermarket operators and maintenance men.

Different ergonomics aspects have to be analyzed according to these groups. For example, customers should easily access food packages, while supermarket operators need also to execute repetitive tasks (e.g., loading a shelf) with postures and movements as safely as possible without causing musculoskeletal disorders and health risks. This means that the designer should also assess postures and movements to ensure a complete and healthy use of the refrigerated unit. Table 1 summarizes ergonomics factors considered for the three categories.[2,3]

Finally, we analyzed tasks commonly performed by envisioned user groups. In agreement with the involved company, we decided to simulate following tasks:

- Customers: reaching & grasping products disposed over the shelves or in a chest;
- Operators: loading a vertical or horizontal unit and the serving a customer;
- Maintenance men: check of electrical equipment.

Table 1. Users' categories and ergonomic factors.

	Customers	Operators	Maintenance men
Comfort			
Visibility			
Reaching/Grasping			
Multi-person interaction			
Strenght assessment			
Part removal/replacement			
Safety analysis			

3. A ROADMAP FOR ERGONOMIC ANALYSIS

The basic idea has been to define and experiment a step-by-step roadmap the designer can adopt to evaluate the ergonomic aspects and analyze alternative configurations of the refrigerated units since the early stage of the product development.

Figure 1 portrays the proposed roadmap based on the use of 3D parametric models representing product archetypes and of virtual humans.

Concerning the set up of the virtual scene, we developed two libraries: one for the refrigerated units and another one for packed food. The first includes 3D parametric models, which are archetypes of units and represent the product families. Each 3D model is a simplified representation of the product where components specifically involved in the ergonomics analysis have been parameterized to be easily modifiable, e.g., shelves sizes (length and width), positions (height from ground) and number. The second library includes a set of 3D parametric models that represents a wide range of products easily adaptable to the specific refrigerated unit. Figure 2 portrays the simplified models and meaningful sizes of a vertical unit for fresh products and of a milk package.

To take into account diversity of people sizes, we considered three sets of virtual manikins to represent consumers' population, the intended operators and maintenance staff. In agreement with involved company, the first set comprises 6 manikins: 2 female (5^{th} and 50^{th} percentiles), two male (50^{th} and 95^{th} percentiles) and two manikins (female and male 50^{th} percentile) sitting on a wheel chair representing people with lower limb disabilities (named "disabled people"). This set permits to cover European population of interest (mainly South Europe) and to evaluate different level of performances with respect to each selected percentiles.

The second set consists of two manikins corresponding to a 50^{th} percentile female and a 50^{th} percentile male, and the last two manikins corresponding to 50^{th} and 95^{th} percentile male.

Simulations have been planned taking account ergonomic factors and the different needs of the final end-users and, when necessary, of the international standards for machinery workers. To model virtual humans and realize simulations we adopted the commercial software package Jack.[10]

In the following section, we will describe main results obtained and their evaluation.

4. SIMULATION RESULTS AND EVALUATION

To verify potential of ergonomic analyses with virtual human, simulations have been performed for the five types of refrigerated units included in the library, varying parameters such as shelves positions and number.

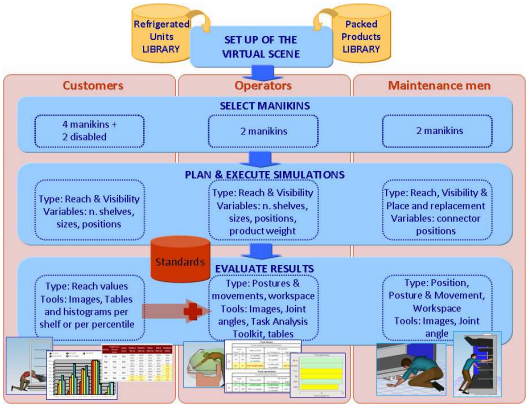

Figure 1. Roadmap for ergonomics analysis with digital human models.

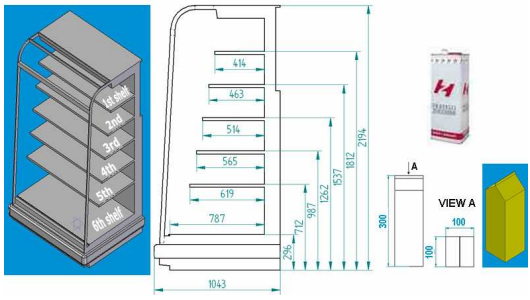

Figure 2. 3D Models of a vertical unit for fresh products and of a milk package.

4.1. Customers' Ergonomic Analysis

Regarding customers' group, ergonomic factors mainly concern reaching-grasping and visibility of food packages placed over the shelves. As packed food, we have considered a two-yogurt package, a can, and a milk package having weight less than 1 kg and varying the sizes according to the shelves ones. As said, we have selected six manikins from the anthropometric database, two of which representing a disabled female and a disabled male. In this case, there are no specific standards for the posture; therefore, manikins were initially located in front of the refrigerated unit. For each percentile, the analyses have been conducted following a procedure to identify if s/he can reach, grasp and see the product adopting a trial and error strategy.

The results were quantified calculating the farthest distance reachable from the left border of each shelf and respect to the center of manikin hand in order to evaluate product and shelves accessibility. As an example, we present the results obtained for the refrigerated cabinet shown in Figure 2. It has six shelves: the first at 1812 mm from ground and the last at 296 mm. Figure 3 shows the postures obtained for all considered percentile to access products disposed over the 2nd shelf. Table 2 summarizes results obtained for food package reaching where the values have been calculated as above-mentioned. Yellow cells highlight shelves with critical values (reachability less than 50%), which mainly refer to the 1st and 2nd shelf, green ones shelves with an acceptable level of product reaching, and white ones shelves completely reachable. Figure 4 portrays a histogram that summarizes the percentages of product reaching for each percentile with regard to each shelf. One can note that the 4th shelf (height from ground: 987 mm) can be accessible by all considered population, the 3rd, 4th and 5th have values higher than 60%, while the 1st and 2nd are the most critical, especially the first one accessible only by the 95th percentile. The disabled man cannot reach the 1st and 2nd shelves, while the others are partially accessible.

Thanks to the library of the 3D parametric model, it is quite easy to modify meaningful dimensions of the unit or shelves (sizes, location, and number) to find better ergonomic performances. For the customers we do not evaluate the comfort of the posture since they execute the task (access the packed product) occasionally; therefore, a limited set of system functionality can be sufficient and adequate to perform ergonomic analyses.

4.2. Operators' Ergonomic Analysis

For operators, ergonomics analysis concerns also the evaluation of working postures and movements in relation to the refrigerated cabinet; in fact, operators are exposed to repetitive tasks that can cause pain and fatigue. This means that the engineers should design machinery reducing as much as possible painful and tiring postures and movements and thus health risk. Several researches have been conducted in this field[11,12] (www.cdc.gov/NIOSH/) and national and international standards have been established; in particular, we refer to the European Standard UNI-EN 1005-4:2005[13] and UNI EN 1005-5:2007.[14]

Table 2. Reaching values for the vertical unit.

Shelves	Height from ground [mm]	Depth [mm]	FEMALE 5th %ile	FEMALE 50th %ile	MALE 50th %ile	MALE 95th %ile	DISABLED MALE
1st	1812	414	0% 0	2% 10	24% 100	56% 230	0% 0
2nd	1537	463	15% 70	37% 170	55% 260	100% 463	0% 0
3rd	1262	514	62% 320	82% 420	82% 420	100% 514	30% 150
4th	987	565	100% 565	100% 565	90% 510	100% 565	58% 300
5th	712	619	61% 380	70% 430	78% 480	78% 480	53% 330
6th	296	787	64% 500	64% 500	67% 530	66% 520	33% 260

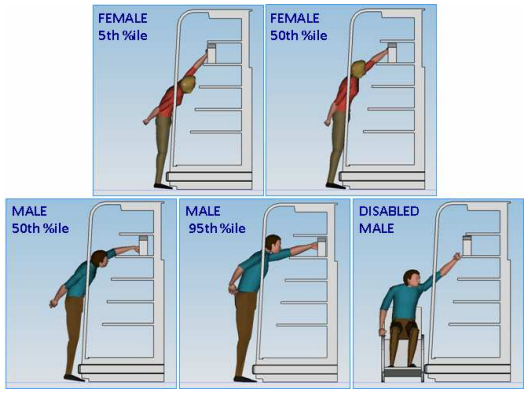

Figure 3. Comparion of manikin postures and reaching & grasping for the 2nd shelf.

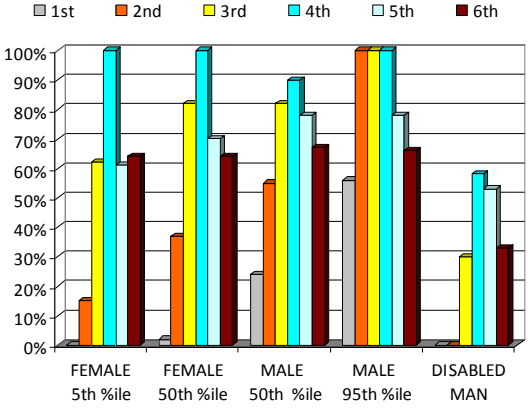

Figure 4. Reaching values for the vertical unit.

As said, we considered two typical situations: the operator loading a vertical or horizontal unit and the operator serving a customer. For both cases, we used two JACK toolkits: the first to determine the spinal forces acting on a virtual human and to verify if worker's tasks respect NIOSH guidelines, the second to evaluate the percentage of a worker population that has the strength to perform a task based on posture, exertion requirements and anthropometry.

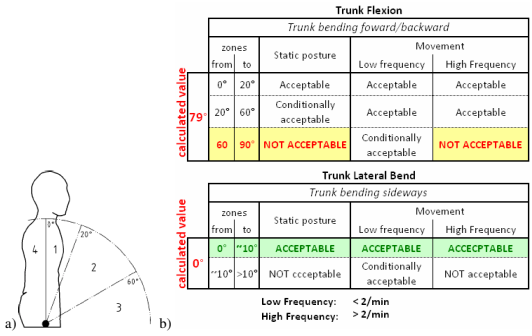

Figure 5. (a) Zone for trunk bending forward/backward[13]; (b) Trunk posture compared with standard rules.

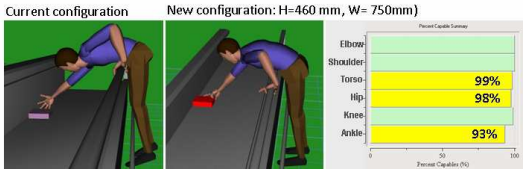

Figure 6. Loading task for the new configuration.

The first test case considers a horizontal refrigerated cabinet and the task accomplished by 50th percentile operator to load the chest with frozen products. We evaluated virtual human's postures to load products taking into account following variables: products place within the chest (e.g., at nearest and farthest edges of the chest and at the middle), product weight (from 1 kg to 4 kg) and chest depth. This last one has been considered to analyze alternative unit configurations that better satisfy ergonomic standards.

The identified postures have been compared with requirements defined by European Standard UNI-EN 1005-4:2005 and UNI EN 1005-5:2007. The standard uses a number of zones to evaluate mentioned and defines values acceptable for low and high frequency movement related to trunk, upper arms, neck, and so on. As an example, Figure 5a shows the four zones considered for the trunk bending forward/backward, while Figure 5b portrays a partial view of numerical data obtained for the operator's trunk posture (flexion and lateral blend) when loading a 1kg product at the farthest edge of the chest compared to the mentioned standards values.

Since some values are not acceptable, other simulations have been performed varying the height (H) and width (W) of the chest in order to find a configuration that meets the regulations. Figure 6 shows a configuration with height equal to 460 mm and width 750mm where data related to ankle improve.

The second test case regards a horizontal serve-over display unit commonly used for fresh meats, deli or cheese. In this case, an operator should be able to access products and serve the customer performing the task according to regulations. We proceeded similarly to the previous case evaluating product reach, related postures/movements, operator working space and the interaction with the customer. Figure 7 shows an example of the identified posture for a female 50th percentile and of interaction customer-operator.

4.3. Maintenance Ergonomic Analysis

Regarding this category, ergonomic simulations have been carried out to study a solution for electric equipment maintenance suitable for different types of refrigerated units. The design solution should allow technicians to access parts and manipulate tools necessary for the task,[3] ensure part removal and replacement, visibility during task execution and technician's safety.

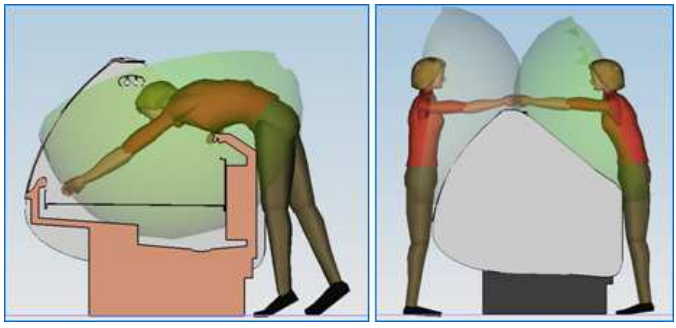

Figure 7. Postures for the horizontal serve-over display unit.

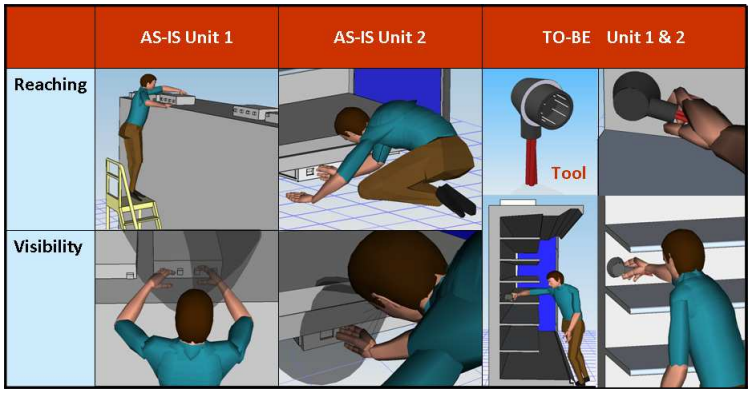

Figure 8. As-Is and To-Be configuration for electric equipment.

A first of set of simulations with the task accomplished by 50th and 95th percentiles operators were performed to analyze existing situation and identify main ergonomic problems. In some units, the equipment was located over the roof; therefore, it was necessary to use a stair and often not all parts were easily reachable and visible by the technician. In other configurations, the electric equipment was mounted close to the floor and technicians had to assume uncomfortable posture to see, access and replace parts (Figure. 7 As-Is).

In agreement with the involved company, we decided to adopt a connector to create a link with electric equipment thus creating an easy accessible checkpoint. A second set of simulations were planned and executed to identify the correct position for the connector link as shown in Figure. 8 (To-Be). The solution has been verified for the different types of refrigerated units with manikins of 50th percentile and 95th percentile.

5. CONCLUSIONS

This paper describes a methodological approach based on the use of 3D parametric model and virtual humans to improve machinery ergonomics and verify the applicability of human modeling system in an industrial context different from traditional ones (automotive or aerospace). Even if, the roadmap recalls classical steps for virtual ergonomic analysis, each of them has been specialized for the specific industrial context identifying necessary tools for an efficient use of virtual humans for the considered industrial application and guidelines on how to perform ergonomic analysis.

It has been experimented with five types of refrigerated unit representing main product families and characterized by different configurations of the shelves and users' interaction modes. Regarding

customers, quantitative data acquired for reaching and visibility are organized in tables and histograms allowing the designer to evaluate rapidly not only the specific machinery but also to compare different types of refrigerated units respect to packed food accessibility and expository space. As far as concern supermarket operators, results from customers' ergonomics analysis (especially postures) can constitute the starting point, but it is necessary to evaluate the comfort and compare operators' postures in order to satisfy national and international regulations and advanced analysis tools have to be adopted.

Our objective has been primarily methodological. The definition of the virtual environment and the planning of the simulations are not particularly complex. On the other hand, it can be a little more difficult defining the correct position and posture of the virtual human and this can lead to wrong results.

ACKNOWLEDGMENTS

The authors would like to thank Dario Cimini, Francesco Baldi, Fabio Arizzi and Rosario Assenza for their contribution in realizing ergonomic simulations.

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