New individual equipment design begins with analysis of the need in order to determine equipment's relationships with its outerspace (including the user himself), transform these relationships into functions, determine their nature (service, strain, etc...). The characterization of the technical functions must be performed in agreement with physiological functions concerned by the equipment. This leads to need in hierarchization, i.e. classification according to importance. If this is not done, requirements of the technical specifications may generate functional conflicts, inconsistencies with user's efficiency and health.

We propose an approach which allows to solve such conflicts for the design of a new chemical protective mask. Its aim is to go far further than simple classical Human Factor approach and to formalize implicated functions hierarchization, thus simplifying dimensioning and integration of design technical factors.

In this paper, we will take chemical warfare protective equipment as examples.
functions, usually measurable), subjective need (estimated function, usually unmeasurable: easiness to dress), interactions and adaptations to outerspace elements (strain functions).

**Technical functions:** («Product» function for the equipment, «Human Factor» for the user): they allow performance of the main functions. For the mask, to allow breathing and airway protection must be done through filtration by canister (protection), permeability to air (breathing) and lowering of air flow resistance in all parts (breathing). They correspond to technical solutions, linked to the manufacturer’s savoir-faire. They may not be visible for the user. A product’s or complex system’s technical functions may be use functions of a part. Each identified criterion is associated with an «appreciation level»: the goal to be reached. Each level has a limit of acceptance, with a «margin» around nominal value.

**Hierarchization of the function**

It allows, from the design phase, an evaluation of the order of importance between functions. Its is referred to an unvariant by one of the conceptors: temporal, technical, emergency, etc. Inclusion in an equipment of a function which ranks N must not penalize any function of higher priority (rank < N). For the protective mask, Medical Officer will choose temporal hierarchization linked to vital functions: to protect breathing, vision, phonation, nutrition. He is interested in the functions of the mask which will become successively a strain and susceptible to lead to health disorders. Fighter chooses an operational hierarchization focused around the efficiency of the user: to allow visual detection, communications, forced-walking, use of firing aids, etc... Designer will hierarchize functions according to acceptance criteria, factory and costs strains. Ergonomist takes into account all these specific hierarchizations, and tries to build up an integrated, concatenated and coherent functional system.

**Dimensional hierarchization**

The value to be taken into account for dimensioning is the one which leads to the higher demand. For breathing: physical exercise ventilation may reach 120 l/min, speaking, drinking, performing apnea need to spend the least time for inhalation and thus to reach maximum inspiratory flow: 10 l/s within 0.5 s (600 l/min.).

**Temporal Hierarchization**

Its aim is to evidence the progressively limiting role of some functions, according to the scheduled use duration. If duration is less than an apnea, there is no need for a breathing system. When duration may become longer (> 30 s.) then the equipment must include a breathing system. Thermal exchanges become limiting only when heat storage is too high (not before 30 min). If activity is to last some hours, there may be a need for urination, which will cause not only discomfort, but also operational limitation.
During an experiment performed in Djibouti, it has been proved that some subjects wearing chemical protective equipment do not drink due to conflict between breathing and drinking. Absorption of 100 ml of water within 30 seconds (NATO requirement) is almost impossible after vigorous exercise. People have to manage the conflict between restoring oxygen debt (increased ventilation), increased inspiratory workload (due to air flow resistances) and performing an apnea after full exhalation (water absorption). Such a temporal hierarchization cannot solve all difficulties.

**Functional Hierarchization**

*It allows, as soon as a design phase is started, to obtain an estimation of the rank of the main and technical functions.*

Functional hierarchization may be scheduled in four steps:
1. list the systemic functions required from the equipment,
2. for every identified technical function, analyze related physiologic, sensory and cognitive ones,
3. hierarchize as a function of utilization,
4. identify and hierarchize involved subpart ergonomic functions.

For instance, let us consider the « mobility » function of a fighter. It is technically qualified as a part of the equipped fighter’s activity. During a mission, it may be very limited (rest) or full sized (movement).

<table>
<thead>
<tr>
<th>RANK</th>
<th>FUNCTION</th>
<th>CRITERIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Breathing</td>
<td>Exercise induces increased breathing demand (up to 120 l/min.). Payment of oxygen debt.</td>
</tr>
<tr>
<td>2</td>
<td>Motricity</td>
<td>There is no move without involvement of motricity (walking, running, driving)</td>
</tr>
<tr>
<td>3</td>
<td>Vision</td>
<td>Movements depend upon visual information; impediment detection</td>
</tr>
<tr>
<td>4</td>
<td>Sudation</td>
<td>Exercise induces heat production, eliminated through sweating, inducing heat strain and water loss. Sweat may impair chemical absorbent material.</td>
</tr>
<tr>
<td>5</td>
<td>Hydration</td>
<td>Compensation of water loss</td>
</tr>
<tr>
<td>6</td>
<td>Nutrition</td>
<td>Compensation of energy expenditure (long delay), psychological aspects</td>
</tr>
<tr>
<td>7</td>
<td>Somesthesia</td>
<td>Adequacy between equipment and body size</td>
</tr>
<tr>
<td>8</td>
<td>Cognition</td>
<td>Mental integration of goals, needing sensitive motor control specific to work situation</td>
</tr>
</tbody>
</table>

*Table 1 : Hierarchization criteria for «Mobility» (fighter dressed with chemical protective equipment).*

Identification of related physiological, sensory and cognitive functions allows to quote, without any rank: motricity, nutrition, vision, breathing, sudation, somesthesia, cognition, and so on. Table 1 is one of the functional hierarchization steps, dealing with mobility, which details the utilized criteria.
Specific relationships link each subpart of the equipment to a «Human Factor» technical function. For instance, out coming hierarchization for the mask seems to follow the same steps than ergonomic function «mobility». In fact, motricity, the rank of which is high in ergonomic functions, is not directly involved in the subpart «mask».

Therefore, for a given «Human Factor» technical function of a main ergonomic function, all subparts are not concerned; ranks for each subpart are not identical and interactions between subparts are not taken into account.

This leads to define a finer analysis of functional interactions, in order to link the hierarchized functions. Combination of ergonomic function hierarchizations allows to take into account the whole scope of human factors functions and ranks, but it is not sufficient, because it does not qualify nor dimension interactions.

The functional hierarchization method allows identification of the needs linked to an equipment and its subparts. It may be sufficient in some circumstances (upgrading of a specific subpart). It does not take into account functions interactions between subparts. Such a linkage may be evidenced by a special step named «Operative Concatenation». It is not compulsory, but remains more often necessary. Full description is beyond the scope of the present paper.

CONCLUSION

Laboratory and field experiments evidenced the limits of equipment designed without identification of operational functionalities, function hierarchization (physiological, sensory and cognitive) participating in their technical design and interactions estimation (function dependence or independence).

This led us to elaborate a functional hierarchization method for protective equipment design. It is based on available techniques, mostly applied in research departments, both R & D (functional analysis) and scientific (statistical analysis of interdependences). Applied from the project beginning, its aim is to improve identification and dimensioning of human factor functions involved in the equipment’s requirements for the required activities to be performed.

REFERENCES


208