INDIVIDUAL EQUIPMENT DESIGN AND ERGONOMICS

Functional Analysis and Function Hierarchization

S. ETIENNE*, G. MAGNAUD**, P. GIRY***

** French Forces Institute of Naval Medicine, BP 610, 83 800 Toulon-Naval (France)*

***French NBC Study Center, 91710, Vert le Petit (France)*

New individual equipment design begins with analysis of tlie need in order to determine equipment's relationships with its outerspace (including the user himself), transforin these relationships into functions, determine their nature (service, strain, etc...). The characterization of tlie 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 coifflicts, inconsistents with user's efficiency and health.

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

In this paper, we will take cheinical warfare protective equipment as examples.

INDIVIDUAL PROTECTIVE EQUIPMENT ERGONOMICS AND FUNCTIONALITIES

Individual protective equipment is designed for preservation of the whole body against a hazard. They can be designed as one-piece full equipment, separate parts (mask, gloves, shoes, suit) to be assembled, or subpart to be integrated in tlie working suit. Global functionality must be in agreement with man's activities during work situation, exposed to tlie hazard (physical, cheinical, biological) he has to be protected against. These may alter health and decrease perforinance. The equipineiit is then an interface, passive or active. It becomes a strain, mainly when the operative functionality has not been considered from the design phase through a hierarchized functional analysis. A function may be defined by the action of one or several elements working towards a final common goal: For instance, a mask which inust «allow breathing during sleep)). Functional analysis must remain independent of the technical ways to solve the problem. Referring to solutions may lead to omit some of tlie fuiictioiialities involved in the need. The functions of a product may be classified in two groups:

Main Functions (((product functions)) for the equipment, ((ergonomic functions)) for the user). They comply with a part of the user's need (in the example of a protective mask: guarantee face protection, breathing, sight, etc...). They are qualified through their description of objective need (employment

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 cheinical protective equipment do not drink due to conflict between breatlung 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 liierarcliization 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 technicalfunctions.

Functional hierarchization may be scheduled in four steps:

1. list tlie systemic functions required from tlie 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).

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

Table I : Hierarchization criteria for «Mobility» (fighter dressed with cheinical 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 hierarchzation 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

Etienne S., Diedzinl P., Pklicand J.Y., Zenou N., Warme-Janville B. 1993. Risque chimique, Environnement tropical et Activité opérationnelle. Deuxièmes Journkes du Commissariat Supkrieur aux Sports Militaires, Fontainebleau.

Gagge P. A. 1983. The science of clothing. Actes de la Confkrence Internationale "Aspects medicaux et biophysiques des vêtements de protection", Lyon.