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A GENERAL APPROACH FOR MAN-MACHINE SYSTEMS DESIGN

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Abstract: The man-machine systems design is a major concern for the computer scientist, the control engineer and the ergonomicist. An adequate design for such systems means optimisation of their performance, which is the result of taking into account the human element since the design stage. Human integration, in the design stage, can strengthen the stability and optimality of all system functions. This paper deals with the problem of man-machine systems design by proposing a general approach based on system analysis methodology, action identification and action specification. All those aspects will be treated in this paper. *Copyright©2002IFAC*

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1. INTRODUCTION

Generally, in the activity's space of all semiautomatic systems three areas of activity can be identified: completely automated activities (realised by machine), completely manual activities (performed by man) and activities which can be performed by man (or machine) with the machine's assistance (man's assistance). The last zone is called "the zone of man-machine activities". Figure 1 shows a graphic representation of these three zones. From this figure, it can be seen that the zone of man-machine activities is situated around a virtual line which divides activity's space into automatic and manual zones. The identification of this zone constitutes the principal idea of man-machine system design.

Before explaining the methodology of identification, it is necessary to define four terms used throughout the paper :

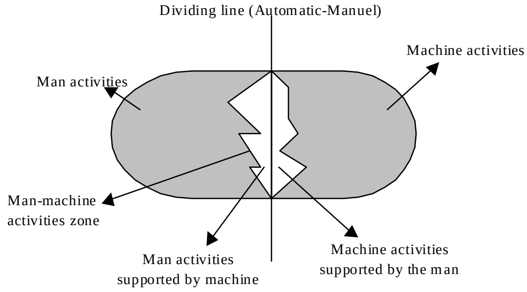

Fig. 1. Activity zones of man-machine system

- Action: represents the effort made to reach a transitory target. One action can be only performed by man or machine.
- Activity: represents a set of actions which lead to the achievement of a sub-objective.
- Task: represents a set of activities which lead to the achievement of an objective.
- Mission: is a set of tasks leading to the achievement of a global objective.

2. SOCIO-TECHNICAL DESIGN: GLOBAL APPROACH

(Millot, 1996) proposed a design methodology for a man-machine system. This methodology is based on two approaches:

- Descendant approach: this approach considers the technical characteristics and the objective of the system to achieve a prototype of a man-machine system.
- Ascendant approach: this approach aims to give a better definition of tasks which can be attributed to humans. This definition is based on human criteria on the one hand, and on system performance on the other.

2.1. Global approach

As is shown in figure 2, the global man-machine system design approach consists of:

- Analysis of control and controlled system: this consists of identifying all actions which have to be performed to reach the system goal. The analysis is accomplished on two functional modes: normal and abnormal. Obviously, this stage become more difficult if we design a new system (based only on specification and technical documentation).
- Actions Analysis: this consists of identifying the actions performed by man and/or by machine. The aim of this analysis is to determine the need of assistance to perform man’s action (eventually the need of assistance to perform machine’s actions). This analysis is principally based on human criteria (mental and physical capacity) and on technical specification of machine (in general meaning of term including information entity) .
- Definition of assistance and automation tools: it is a matter of verification if the realisation of action needs some assistance, and specifying an adequate tool for this assistance. This approach results in three types of design being considered: ergonomic design of post (work post), technical design and man-machine interface design (choice of co-operation modes). Each type of design leads the definition of a category of activities, respectively: man's activities, machine's activities and man-machine activities.
- Definition of man, machine and man-machine tasks (implementation stage): this is a formulation from the set of all activities (man, machine and man-machine activities) the corresponding tasks. After regrouping those tasks in the mission, it will be implemented either in the execution level of socio-technical systems or in their supervision level (skaf, 1999).

As can be seen from this description and from figure 2, the proposed approach is of a general nature. This means that it can give the stages of man-machine system design, without, however, giving the conceptual details for each stage.

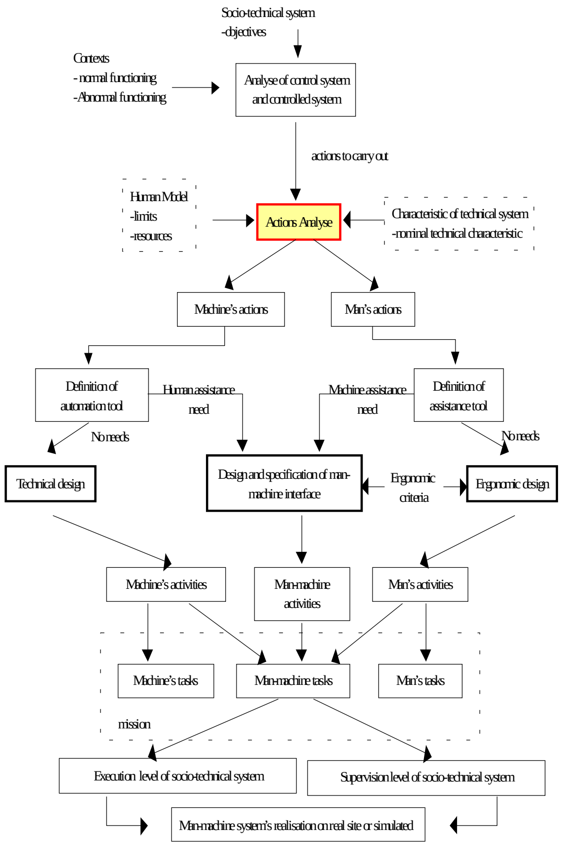

Fig. 2. Global approach for man-machine system design

In this paper, the methodology of action specification will be detailed. This methodology describes the most important stage in global approach called "action analysis".

Before beginning to describe the methodology of specification, it is assumed that analysis of socio-technical systems (using SADT, UML,…) resulted in identifying all actions that lead to achieve system objectives.

2.2. Ergonomic and technical specifications of actions

The aim of specification is to define the actions which have to be achieved by man and, respectively, by machine. This simplistic idea masks a very complicated problem within the analysis method. Thus, the question is: how can a reference model be created to specify the action? To deal with this problem, the method of specification has to propose a set of ergonomic and technical criteria. According to these criteria, each action will be referenced to decide if its realisation will be achieved by man or by machine. Before starting the description of specification methodology, it is advisable to note that the proposed method is approximate because of integration of human aspects.

Assume that there is a set of actions to be specified (to be marked as man or machine action). For this purpose, each action should be considered as a function of two functions, thus a given action called "***Action***" can be expressed like: ***Action(x=f(u),y=f(v))***. It is assumed that this function is defined on [0,1].

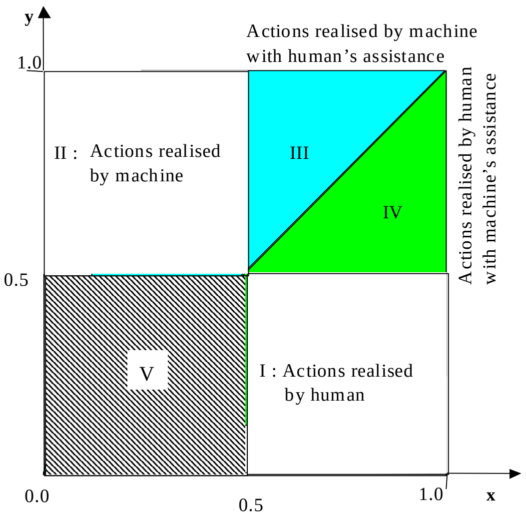

Fig. 3. Graphical representation of sectors to which actions belong.

The function ***x=f(u)*** $\in[0,1]$ represents a suitable degree of realisation (for the corresponding action) considering a given human model. Likewise, the function ***y=f(u)*** $\in[0,1]$ represents suitable degree of realisation (for the corresponding action) considering a given machine model (a set of technical data). Thus, the values of **x** and **y** determine the sector to which an action considered belongs. Figure 3 shows the five sectors to which any action has to belong to (in this figure the x-axis represents man and the y-axis represents the machine):

- Sector I: all actions belonging to this sector are considered to be man's actions (i.e. their realisation by man is more advantageous). This case is valid when the values of **y** belonging to [0,0.5[and the values of $\mathbf{x}\in[0.5,1]$ (see figure 3).
- Sector II: all actions belonging to this sector are considered to be machine actions (i.e. their realisation by machine is more advantageous). This case is valid when the values of **x** belonging to [0,0.5[and the values of $\mathbf{y}\in[0.5,1]$ (see figure 3).
- Sector III: this sector contains all actions performed by machine with human assistance. In this sector, for **y** values belonging to [0.5,1] the values of $\mathbf{x}\in[0.5,1]$ (considering $y \geq x$) represent the assistance degree (level) contributed by man to accomplish the realisation of the corresponding action. For example, **x** =0.5 of the given action shows that human assistance, for its realisation, is not really required (the action is nearly automated). However, if **x** =1 this means that human assistance really is necessary (nearly shared realisation).
- Sector IV: This sector contains all actions performed by man with machine assistance. In this sector, for **x** values belonging to [0.5,1] the values of $\mathbf{y}\in[0.5,1]$ (considering $x \geq y$) represent the assistance degree (level) contributed by the machine to accomplish the realisation of the corresponding action. For example, **y** =0.5 of the given action shows that machine assistance, for its realisation, is not really required (the action is nearly manual). However, if **y** =1, this means that machine assistance really is necessary (nearly shared realisation).
- Sector V: represents all actions with **x** and **y** $\in[0,0.5]$ at the same time (i.e. for $\mathbf{x}\in[0,0.5]$: **y** $\in[0,0.5]$ and vice versa). The actions belonging to this sector are considered to be non specifiable actions (i.e. there is insufficient information to decide if they can belong to one of another sector: I, II; II and IV). In this paper, it is assumed that all studied actions belong to sector I, II, III and IV.

Thus, to specify the actions, it is sufficient to find **x** and **y** for each one. Consequently, the question becomes: how can the values of **x** and **y** be found?. Before answering this question, two remarks have to be considered:

1. The aim of action specification is to be able to judge the realisation aspects of the action (how?, what effort?, what means, for what price? etc..). This makes it possible to decide which actor can perform it, and also to define the form of assistance if necessary. Therefore, it can be concluded that the context of the

analysed system (environment, evolution, means) affects the judgement. This fact makes the specification method an approximate one.
2. The numbers used to express an approximate definition have a symbolic meaning (i.e. in their place the symbols can be used). Using numbers merely simplifies the reasoning.

To deduce the expression of function **x**=***f(u)*** it is assumed that the initial value of **x** equals $\mathbf{x}_0 = 1$, that means (see above) the action can be performed by man. On another hand, assume the set of criteria *(A, B, C,................N)* which affects the value of **x** by reducing it by Ω proportional to its initial value. Thus, after application of the criteria, the value of **x** becomes:

$$\mathbf{x} = \mathbf{x}_0(1-\Omega) \quad (1)$$

where is Ω less than or equal to 1.
Assume that each criterion affects independently **x**, the expression of Ω will be:

$$\Omega = \sum_{i=A}^{i=N} \gamma_i \quad (2)$$

where $\gamma_i \in [0, 1]$ is the influence of i criterion i∈*(A, B, C,...........N)*. This influence reduces **x** by :

$$\tau_i = \gamma_i \mathrm{x}_0 \quad (3)$$

To keep the value of Ω within the interval [0,1] reserving the influence percent of each criterion, an coefficient α will be introduced :

$$\alpha = \min\left(1, \frac{1}{\sum_{i=A}^{i=N} \gamma_i}\right)$$

Taking into account this coefficient, the expression (1) will be written as :

$$\mathbf{x} = \mathbf{x}_0(1-\alpha.\Omega) \quad (4)$$

Replacing the expressions of Ω and α in (4), the expression of **x** becomes:

$$\mathrm{x} = \mathrm{x}_0\left(1 - \min\left(1, \frac{1}{\sum_{i=A}^{i=N} \gamma_i}\right).\sum_{i=A}^{i=N} \gamma_i\right) \quad (5)$$

γ_i are the coefficients which translate the influence of each criterion on x value by reducing it by γ_i percent of its initial value. Thus, to find the value of x for a given action (in a given context and for a given human model) it is enough to find those coefficients.
The same reasoning for the function y=f(v) leads to determination of the value of y :

$$\mathbf{y} = \mathbf{y}_0(1-\Psi) \quad (6)$$

where $\mathbf{y}_0=1$ is the initial value of **y**. Ψ is the influence of a set of technical criteria *(a, b, c,..............,n)*.
Assume that each criterion affects independently **y**, the expression of Ψ will be:

$$\Psi = \sum_{i=a}^{i=n} \zeta_i \quad (7)$$

where ζ_i [0, 1] is the influence of i criterion i∈*(a, b, c,............,n)*. This influence reduces **y** by:

$$\sigma_i = \zeta_i \mathrm{y}_0 \quad (8)$$

To retain the value of Ψ within the interval [0,1] reserving the influence percent of each criterion, an coefficient β will be introduced :

$$\beta = \min\left(1, \frac{1}{\sum_{i=a}^{i=n} \zeta_i}\right)$$

Taking into account this coefficient, the expression (6) will be written as :

$$\mathbf{y} = \mathbf{y}_0(1-\beta.\Psi) \quad (9)$$

Replacing the expressions of Ψ and β into (9), the expression of **y** becomes :

$$\mathrm{y} = \mathrm{y}_0\left(1 - \min\left(1, \frac{1}{\sum_{i=a}^{i=n} \zeta_i}\right).\sum_{i=a}^{i=n} \zeta_i\right) \quad (10)$$

ζ_i are the coefficients which translate the influence of each criterion on the value of y by reducing it by ζ_i percent of its initial value. Thus, to find the value of y of a given action (in a given context and for a given machine model) it is enough to find these coefficients.

To find either γ or ζ a reference model of data for each criterion is needed. In this paper five criteria only are considered: work load, security and reliability as ergonomic criteria. Cost and feasibility as technical criteria. Next, references data models for these criteria will be established.

2.3. Work load

According to work psychologists, work load is a reliable index for estimating the mobilisation state of an individual. Thus, this index can be used to decide if an action can be easily performed by man. To reach this goal, the modified scale of Cooper Harper (quoted in Millot,1988) can be used in the way shown in figure 4.

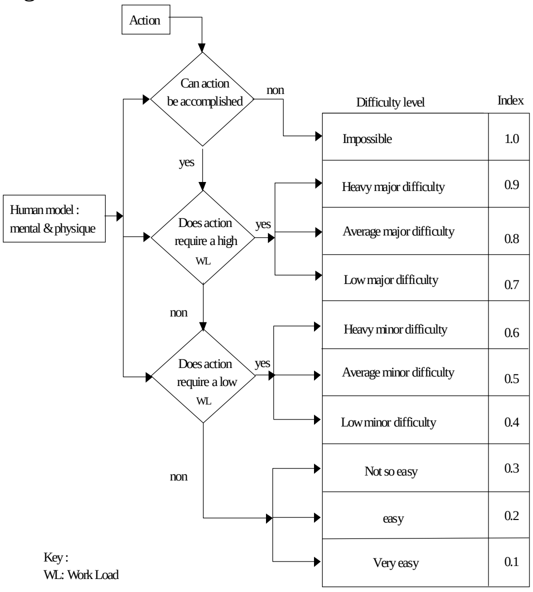

Fig. 4. Modified scale of Cooper Harper adopted for action specification

So, to find the coefficient $\gamma_{wl,}$ each action will be compared (from its realisation point of view) to 10 levels of difficulty (considering a mental and/or physical human model). Each level is indicated by an index $\gamma_{wl.}$

2.4. Security

Security is a very important criterion in deciding whether a human can perform a given action or whether this action must be performed exclusively by machine. For this criterion, a simplified model of reference has been adopted. This model is shown in table 1, where an action can be either dangerous or not. If not, protection may or may not be provided when it is performed. According to the case, the coefficient γ_s can take one of the following arbitrary values: 1.0, 0.2, 0.0 . (see table 1).

Table 1: Estimated values of influence coefficient γ_s of the "security" criterion

Action ➡ *affects* ⬇ *x function*	*Dangerous Action*	*Non dangerous Action with protection*	*Non dangerous Action without protection*
γ_S	1.0	0.2	0.0

2.5. Reliability

In this paper, reliability is considered as an anticipatory estimation of achievement result. So, it can show individual aptitude to be involved in the realisation of action. For this criterion, a simplified model of reference has been adopted. This model is shown in table 2. According to this model, the coefficient γ_R can take one of the following arbitrary values : 0.1 (very reliable), 0.3, 0.5, 0.7, 0.9 (not reliable). (see table 2).

Table 2: Estimated values of influence coefficient γ_R of the "reliability" criterion

Reliability of action realisation	*Corresponding sub-intervals*	*Estimated value of* γ_R
Non reliable	[0.8-1.0]	0.9
A little reliable	[0.6-0.8[	0.7
Average reliable	[0.4-0.6[	0.5
reliable	[0.2-0.4[	0.3
Very reliable	[0.0-0.2[	0.1

2.6. Feasibility and cost

Feasibility and cost are the technical criteria considered to answer the question: can a machine perform the action?, and how much will that cost?. The reference models of both these criteria are shown in tables 3 and 4. According to machine model, each action can be either automated, automated with human assistance or not automated. Thus, the values of coefficient ζ_F can be 0.0, 0.5 or 1.0 (see table 3).

Table 3: Estimated values of influence coefficient ζ_F of the "feasibility" criterion

Nature of action	*Estimated value of* ζ_F
Automated	0.0
Automated with assistance	0.5
Not automated	1.0

In the same way, according to the price of automation (which can be determined according to the economical and environmental context), an action can be fully automated, semi-automated or not at all automated. The corresponding values of ζ_C are 0.0, 0.5 and 1.0. (see table 4).

Table 4 : Estimated values of influence coefficient ζ_F of the "cost" criterion

Choice of action realisation	*Estimated cost*	*Estimated value of* ζ_C
Automatic	low	0.0
Free	average	0.5
Not automatic	high	1.0

3. CASE STUDY

To illustrate the specification method, a “man-tap” system (quoted in (Coutaz,1990)) will be considered. The aim of this system is to fill a bath with tepid water having two taps (one for hot water and another for cold water).
Modelling this system using the well-known method SADT leads us to determine the main actions to carry out (we only consider the normal functioning mode) which are:

- ***To pour***: this action can be supported by man, and/or by the control system (automata). The outputs are the hot water flow rate Fh and the cold water flow rate Fc.
- ***To measure***: this action can be supported by man and/or temperature detector. The output is tepid water.

So, our aim is to design a “man-tap” system, where human limits and needs are respected and the technical and economical aspects of the system are taken into consideration.
From the human point of view, this system is presented by the hot water rate flow Fh, cold water rate flow Fc and temperature T. These three variables are psychological variables which express the aim of the system (to obtain tepid water). Therefore, man can control T by acting on Fh and Fc (open/close the taps for hot water and cold water). Thus, he performs the actions to pour, and to measure.
On another hand, today technology allows this system to be fully automated, but at what price?
To specify these two actions, or to properly design this system, we will calculate **x** and **y** for each action taking into account only two ergonomic criteria: safety and reliability and only two technical criteria: feasibility and cost. Thus, by applying the method described above, the following result can be obtained:

1- It is too hard to control temperature using two taps (one for hot water and one for cold water). For this purpose, the influence (γ_R) of reliability on **x** assume take a high value (the approximately estimated value for a person with good mental and physical capacity is 0.3). On the contrary, the influence of safety γ_s is zero (there are no major risks involved when using taps). When fully automated, this action demands installation of automata. This decision is feasible (ζ_F =0.0) but the cost is too high (ζ_C = 1.0), that means (applying the equation 10) this action is a human one (**y**=0). As it is difficult (for man) to control T using two taps, anther solution can be proposed. This solution consists of installing a mixer tap. This solution is feasible (ζ_F =0.0) and the influence of cost ζ_C is zero (general case). Therefore, applying equations 5 and 10, the **x** and **y** of action **to pour** will be : **x**= 1-(0.3+0.0)1=0.7 ; **y**= 1-(0.0+0.0)1=1, which means this action (**to pour**) will be performed by machine (mixer tap) with human assistance (open/close) (see figure 3).
2- It is not easy to measure temperature (it might be painful), thus the action **to measure** can be considered as a non dangerous action with protection (coefficient γ_S will be 0.2). This action is reliable (the hand is always used to check if the water is tepid) which leads to considering the coefficient γ_R=0.3. On another hand, it is not difficult to install a detector (coefficient ζ_F =0.0), but the influence of cost ζ_C could be 0.5. Therefore, if we apply equations 5 and 10, the **x** and **y** of action **to measure** will be: **x**= 1-(0.2+0.3)1=0.5; **y**=1-(0.0+0.5)1=0.5. This leads us to conclude that this action can be automated (installation of a temperature detector), but considering price, this action will be performed by man. (using a hand is cheaper than a detector) (fig.3).

4. CONCLUSION

In this paper, a general approach of man-machine system design was proposed. The methodology of action specification was described, focussing on ergonomic and technical action specification. A set of reference models for considered criteria (technical and ergonomic) was proposed. Finally, an illustrative example was discussed.
The proposed design method is based on an approximate estimation to identify man and machine actions. One of the future directions for this work is to improve this approximate methodology. Another perspective would be to enhance and complete criteria reference models. Also, further work should study the remaining aspects of the general approach of socio-technical system design such as definition of assistance tools, automated tools,..etc.

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