Association for Information Systems
AIS Electronic Library (AISeL)

PACIS 2011 Proceedings

Pacific Asia Conference on Information Systems (PACIS)

9 July 2011

Human-Machine Function Allocation In Information Systems: A Comprehensive Approach

Fang Liu
Renmin University of China, liufang87@ruc.edu.cn

Meiyun Zuo
Renmin University of China, zuomy@ruc.edu.cn

Ping Zhang
Syracuse University, pzhang@syr.edu

ISBN: [978-1-86435-644-1]; Full paper

HUMAN-MACHINE FUNCTION ALLOCATION IN INFORMATION SYSTEMS: A COMPREHENSIVE APPROACH

Fang Liu, School of Information, Renmin University of China, Beijing, China, liufang87@ruc.edu.cn

Meiyun Zuo, School of Information, Renmin University of China, Beijing, China, zuomy@ruc.edu.cn

Ping Zhang, School of Information Studies, Syracuse University, Syracuse, NY, USA, pzhang@syr.edu

Abstract

In the past, information systems development methodologies primarily focus on whether the needs of an organization could be met. In recent years, several human-centered systems development methodologies are developed to emphasize both organizational and human needs. In addition to an information system being useful, its usability become a central concern, and user analysis and task analysis are important parts in these methodologies. Human-machine function allocation is an important aspect of task analysis. Yet, current research and practice in this area show a gap for systematic and consistent guidelines and approaches. To address this gap, this paper proposes three guidelines and a comprehensive approach for human-machine function allocation when designing organizational information systems. Built on Price's decision matrix, Levels of Automation, and the Analytic Hierarchy Process (AHP), our approach consists of four steps in determining human-machine function allocation. To illustrate this approach, an application example is provided.

Keywords: Human-Computer Interaction, Human-Centered Information Systems Development, Human-Machine Function Allocation, Analytic Hierarchy Process (AHP).

1 INTRODUCTION

Past information systems development methodologies focus primarily on the usefulness of an information system. Usefulness is largely concerned with whether an information system can support an organization's needs. Such methodologies often overlooked the needs of the actual users of the information system.

With the advancement of technology, the technical restrictions that limit the implementation of system functions are much less than they are used to be, and with the increasingly broad user base for information systems, the emphasis of information systems development methodologies has shifted from focusing on usefulness to focusing on both usefulness and usability. Usability is defined as how well users can use the functionality or utility of a system (Nielsen 1993). In order to increase the usability of information systems, human-machine interaction has aroused the attention of scholars, and human-centered system development methodologies are developed in recent years (Iivari & Iivari 2011). Task analysis is an important part of many human-centered development methodologies (Iivari & Iivari 2011). What computers do and what humans do should be distinguished in task analysis (Zhang et al. 2005; Te'eni et al. 2007). In fact, back in 1951, the concept of human-machine function allocation was already proposed by Fitts (1951), which means the division of responsibilities between man and machine.

Human-machine function allocation affects usability and should be carefully studied and practiced. In reality, however, the most common human-machine function allocation approach is the "left-over" approach: functions would be allocated to machine as long as the automation was not too difficult or expensive, and the remaining functions would be allocated to human. This approach has an assumption that computer is more effective than humans. However, the role of human is imperative and the danger of dehumanizing and displacement should not be neglected (Wiener 1988). Moreover, the "left-over" approach focuses on the lower-level responsibilities of users, which can hardly form a coherent set of tasks for users (Butler 1996). It is obvious that human factors should be taken more into concern in the study of human-machine function allocation.

The cost of developing information systems should also be considered. As shown in Figure 1 (Sheridan 2000), there is a range for very simple tasks where machine takes more time than human because of the resources required to set up and teach the computer. While without a complicated process of learning, human could complete these simple tasks less expensive and more efficient. Like the roll-over accident analysis in the railway information systems which occasionally happen. There is also a range of tasks where programming the computer is high cost in the current technological conditions, such as the creative tasks or the tasks requiring communication face to face, that could be better performed by human. However, for tasks of intermediate complexity, the programming time can be amortized over many repetitive operations, and the performance of machine is better than human (Sheridan 2000).

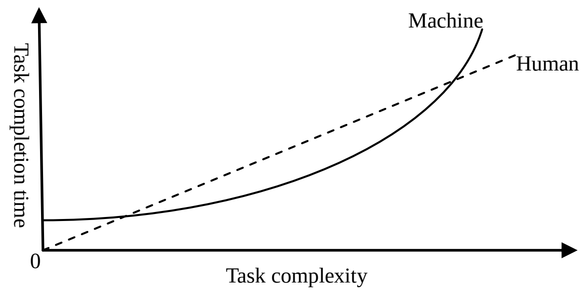

Figure 1. Advantages of automation for tasks of intermediate complexity

As discussed above, a reasonable human-machine function allocation is required to achieve useful and usable information systems. However, it is unclear what guidelines should be followed in the human-machine function allocation process, and what method should be used when allocating functions between human and machine for the information systems. Based on the analysis of related work, this paper puts forward a set of human-machine function allocation guidelines, proposes a comprehensive approach, and provides an example to illustrate the proposed approach. This study has direct contribution to research on human-centered information systems development.

2 RELATED WORK

Existing human-machine allocation methods can be classified into two types: quantitative and qualitative methods. Qualitative methods include MABA-MABA list, Price's decision matrix, scenario-based methods, and methods based on automation types and levels. Among others, while quantitative methods include AHP (The Analytic Hierarchy Process). Several major human-machine allocation methods are briefly introduced here.

2.1 The MABA –MABA List

Fitts (1951) introduced this method in his research on human engineering for air-navigation and traffic-control systems in 1951. This method is also called MABA-MABA (Men Are Better At & Machines Are Better At) method. The main idea of this method is to compare the relative ability of human and machine, then find the capabilities and limitations of both human and machine before the determination of the optimum division of responsibility. Based on the comparison, a list of the advantages of men and machine, called the MABA-MABA list, is developed. This list provides the proper scientific basis for following research on the allocation of functions between human and machines (Sheridan 2000).

However, this method has limitations. Fitts admitted that this method cannot take into account the context of work, and does not consider the fact that the dynamic flow of information can affect the user's knowledge of work status (Fitts 1962). Moreover, the MABA-MABA list has little impact on engineering design practice because such criteria are overly general and non-quantitative (Price 1985).

2.2 Price's Decision Matrix

The MABA-MABA list assumes that functions can be performed by humans or machines alone, which is incompatible with engineering principles (Price 1985). Price's pointed out that a logical error of some allocation methods is an assumption that if a human is a poor controller, then a machine must necessarily be a good one. Yet in fact, there are tasks that neither human nor machine can do well, while there are other tasks that both can do superbly (Price 1985). Jordan (1963) also pointed out that men and machines are complementary, rather than comparable. "Once the problem is so reformulated, new ways of thinking which appear to be promising open up" (Jordan 1963 p.161). On the basis of the above discussion, the Price's decision matrix method was proposed.

Price's decision matrix represents a decision space in which the x-axis is the judgment variable of performance of humans, scaled from unacceptable to excellent, and the y-axis is the corresponding variable of performance of machines, as shown in Figure 2. The performance of any functions can be represented by a point in the decision space. Price's decision matrix is composed of six zones that are qualitatively different in their implication for allocation of functions.

However Price did not explain how to judge the performance of humans and machines explicitly. The description of the allocation scheme of the six areas is ambiguous as well. As a result, this matrix can hardly be used in the engineering design practice.

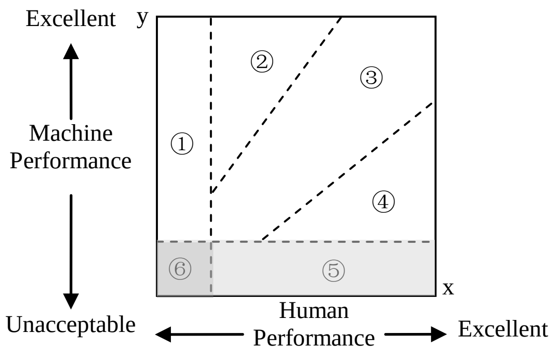

Figure 2. Price's decision matrix

2.3 Types and levels of human interaction with automation

A model for types and levels of human interaction with automation was proposed by Parasuraman (Parasuraman & Sheridan 2000), and could be implemented in the industrial automation systems, such as Air-traffic control systems. This model suggests that automation can be classified into four types: 1) information acquisition 2) information analysis 3) decision and action selection 4) action implementation. And automation can vary across a continuum of levels, from the lowest level of fully manual performance to the highest level of full automation, as shown in Table 1.

HIGH	10	The computer decides everything, acts autonomously, ignoring the human.
	9	Informs the human only if it, the computer, decides to
	8	Informs the human only if asked, or
	7	Executes automatically, then necessarily informs the human, and
	6	Allows the human a restricted time to veto before automatic execution, or
	5	Executes that suggestion if the human approves, or
	4	Suggests one alternative
	3	Narrows the selection down to a few, or
	2	The computer offers a complete set of decision/action alternatives, or
LOW	1	The computer offers no assistance; human must take all decisions and actions.

Table 1. Levels of Automation

Parasuraman then proposed a framework that outlines a process of function allocation applying the model of types and levels of automation. This framework emphasizes that the initial level of automation should be evaluated by the primary evaluative criteria of human performance in conjunction with secondary evaluative criteria of reliability and costs, and be adjusted if necessary. The process is repeated until the final types and levels of automation are determined.

The framework is not a formulaic approach. The process of choosing the types and levels of automation mainly depends on subjective judgments. In addition, some levels of the ten automation levels are very similar to each other. For example, the differences among level 7 to level 10 are whether the human is informed and in what ways the human is informed. At the time of applying this approach, the automation levels may need to be adjusted.

2.4 A method based on scenarios

This method was proposed by Dearden etc. from University of York, was developed and evaluated in collaboration with British Aerospace, and was tailored for the design of single-seat aircrafts (Dearden et al. 2000). The method takes into account a set of assumptions about situations into which a system will be deployed. For example, a scenario of bird strike would be considered in the design of single-seat aircraft. In addition, the method also considers the tradeoffs between cost and benefit of allocation and the support of emergent tasks. Finally, similar to the method proposed by Parasuraman, this method suggests iterations of allocation until a satisfactory scheme can be found.

Despite the focus on scenarios, not all factors of scenarios are considered and some of these factors may affect the operation of information systems, such as the physical environment where the server is placed and the knowledge or skills of the users. Therefore, it is a challenge to not ignore those factors of scenarios when allocating the functions of information systems between human and machine.

2.5 The Analytic Hierarchy Process

While the above introduced methods are all qualitative in nature, AHP (the analytic hierarchy process) is a quantitative method. Quantitative methods can be more objective, which complement some of the limitations of the qualitative methods. Classical probability theory also could be used to build function allocation model (Zhou & Zhou 2003).

AHP was proposed by Saaty in the early 1970s in response to allocating scarce resources and planning needs for the military. AHP has three steps: (1) build a hierarchy model, which consists of an overall goal, a group of alternatives and a group of criteria; (2) ask experts to analyze the model through a series of pair-wise comparisons of the criteria against the goal for importance and pair-wise comparisons of the alternatives against each of the criteria for preference; and (3) calculate the pair-wise comparison matrices mathematically and derive the weights and priorities for each node of the hierarchy model (Saaty 1980). Besides, AHP provides a useful mechanism for checking the consistency of the evaluation measures and alternatives suggested by the experts, reducing bias in decision making. In the field of information systems, AHP is used to prioritize different forms of information (Cheng & Li 2001).

AHP can also be used to find the most suitable team members to work on a task based on his or her skills, experience and workload (David & Mak 2006). Some scholars applied AHP to evaluate the human-machine performance so as to allocate human-machine functions in an intelligent fire and command control system (Tang et al. 2008), unmanned aerial vehicles control stations (Yi et al. 2007), and manned spacecraft cockpit devices (Yang et al. 2007). However, the AHP application area mentioned above are mainly industrial automation systems instead of information systems, so the criteria used in their hierarchy models may not be suitable for the function allocation in information systems.

2.6 A Summary

As introduced above, Price's decision matrix does not explained how to calculate the performance of human and machine, while AHP is an effective method to determine the human-machine performance, although the criteria may need to be built according to the characteristics of information systems. The description of the allocation scheme of the six areas in Price's decision matrix is ambiguous, while the levels of automation proposed by Parasuraman elaborate the possible human-machine function allocation scheme, although the ten levels may not be entirely suitable for information systems.

To focus on information systems, we combine AHP and levels of automation with Price's decision matrix to propose a comprehensive human-machine function allocation approach In addition, we include the scenarios where the information systems are used and consider the process of function allocation to be a recursive or iterative process. Next, we will outline the principles that guide the approach. Then we provide a detailed description of the approach, followed by an illustration of applying it in a particular information systems development.

3 THREE GUIDELINES

The previous studies of function allocation have their own advantages and disadvantages respectively. When allocating human-machine functions of information systems, we can make a comprehensive analysis based on the advantages of the previous work. Actually, three guidelines of function allocation can be summarized from the existing work:

1) Human and machine comparison: Compare the abilities of human and computer, and allocate the functions in an objective and logical way. For example, the regular, monotonous, repetitive and high-end computing work could be allocated to systems. While the tasks of input, design, creation, maintenance and coping with emergency should be assigned to human (Fitts 1951).

2) Cost focus: Allocate the functions of human and machine according to the comparison of cost and benefit (Dearden et al. 2000). Different from the guideline of "Human and machine comparison", this principle take cost factor into consideration. If a specific function was allocated to information systems, the cost of design and development of information systems would increase. If the task were undertaken by human, the cost of training would not be ignored.

3) Human-centeredness: We should improve the satisfaction of users as much as possible when allocating functions of information systems. This guideline would play a leading role in the future research of information systems development methodologies. To increase the satisfaction of users, the functions in some systems could be either allocated to human or to machine, and allow users to decide upon allocation of functions when operating (Kantowitz & Sorkin 1987). Some scholars suggested the allocation of functions between human and machine should be suitable to physiological and psychological needs of people, facilitating the realization of individual values (Xu et al. 2004), which also reflects the guideline of "human-centeredness".

The above three guidelines can be used to guide the function allocation in information systems, which should be reflected in the human-machine function allocation approach.

4 A COMPREHENSIVE HUMAN-MACHINE FUNCTION ALLOCATION APPROACH

Our approach reflects the three guidelines above. In addition, our approach extends the strengths and overcomes the limitations of the existing methods. There are four steps in the process of allocating functions:

1. Construct the hierarchy model based on AHP.
2. Calculate pair-wise comparison matrices based on the judgments of experts.
3. Determine the value of x-axis and y-axis for Price's decision matrix to determine the levels of function allocation.
4. Decide the initial human-machine function allocation scheme, invite users to evaluate this scheme with a prototype system in a specific scenario and adjust the allocation scheme recursively.

4.1 Construct the hierarchy model

AHP classifies the elements related to allocation decisions into three hierarchies: goal, criteria and alternatives. The design of the hierarchy model is as follows.

4.1.1 Design of goal

The IS Success Model suggests that the success of information systems depends on three factors: system quality, information quality and service quality. Usability is an important factor concerning information quality and system quality (DeLone & McLean 2003). The allocation of functions between human and machine would affect usability (Butler 1996). Thus the goal of the hierarchy model of function allocation of information systems could be: Increase the usability by allocating functions between human and machine. In practise, the goal should be specified according to the objective and the requirements of developing the information systems.

4.1.2 Design of criteria

The levels of criteria can be constructed on the basis of usability metrics provided by existing research. Usability is defined as: "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use"

(ISO9241/11 1998). CIF (Common Industry Format for Usability Test Reports 2001), proposed by NIST (National Institute of Standards and Technology) in US, also adopts the same definition, and puts forward three types of metrics to measure usability: effectiveness, efficiency and satisfaction. The efficiency part contains three sub-metrics: completion rate, errors and assists (CIF 2001).

Based on the usability metrics in CIF, we design the criteria to evaluate human-machine function allocation of information systems to be consistent with the usability metrics in CIF: effectiveness, efficiency and satisfaction. The criteria of effectiveness and efficiency are relatively objective, requiring experts to determine by comparing human and machine. These two criteria reflect the guideline of "human and machine comparison". And the criterion of satisfaction reflects the "human-centeredness" guideline.

There are three sub-criteria of efficiency in CIF: completion rate, errors and assists. It is noted that errors and assists have a negative connotation while completion has a positive one. When comparing the alternatives, experts might get confused because they have to make judgments from two opposite directions. To avoid confusions and potential errors, we rename the two negative criteria to describe them in a positive way: error is replaced by correctness, and assists is replaced by independency.

Furthermore, according to the guideline of "cost focus", cost should also be included in the level of criteria of the hierarchy model. In a summary as shown below, the criteria of the hierarchy model have objective factors (effectiveness, efficiency), subjective factors (satisfaction), and economic factors (cost).

1) Effectiveness: relates to the goals of using the product to the accuracy and completeness. It does not take into account of how the goals were done, only relate to the extent to which they are achieved. Common measures of effectiveness include percent of task completion, correctness and independency of performing a task.

a. Completion: When tasks cannot be divided into sub-tasks, the completion rate is the percentage of users who completely and correctly achieve each task goal. If goals can be partially achieved, the criterion may also be scored on the percentage of completeness of a certain task.

b. Correctness: This criterion of correctness is measured by numbers of errors occurred when users performing assigned tasks. The less the numbers of errors are, the higher the criterion is.

c. Independency: Independency is measured by the numbers of using support tools such as online help or documentation, when users encountered difficulties and can hardly proceed on their tasks. The less the numbers of assists are, the higher the criterion of independency is.

2) Efficiency: relates to the level of effectiveness achieved compared to the quantity of resources used. Efficiency describes the mean time taken to complete each task. Using an efficient system, users can complete their tasks with less time.

3) Satisfaction: describes a user's subjective response when using the product. User satisfaction can be an important motivation to use a product.

4) Cost: is the expense based on a particular function allocation, including cost of the development of information systems as well as the cost of training users.

4.1.3 Design of alternatives

The weights of the alternative level should be used as the value of x-axis and y-axis in Price's decision matrix in our method. Thus only two extreme alternatives (wholly allocate to human and wholly allocate to machine) of human-machine function allocation are required in the alternative level of the hierarchy model. In practice the alternative should be particularized in line with the requirements of information systems.

As a summary, the hierarchy model is shown in Figure 3:

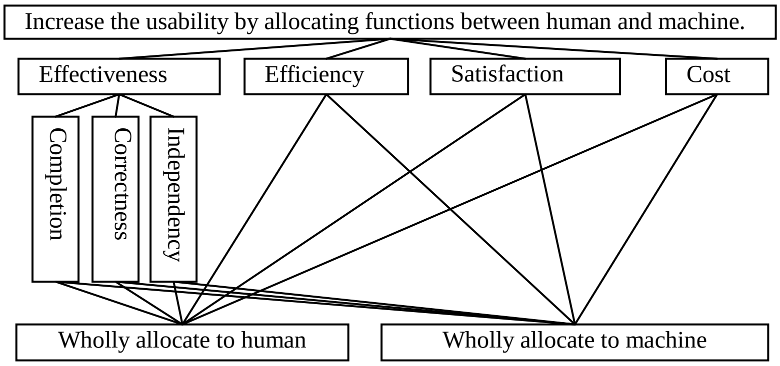

Figure 3. The hierarchy model of function allocation

4.2 Design questionnaire and calculate pair-wise comparison matrices

The nodes of the same level in the hierarchy model should be pair-wise compared on a scale from 1 to 9, and the pair-wise comparison matrices should be constructed. The value of the pair-wise comparison matrices is obtained from experts through a questionnaire.

In the questionnaire, experts should judge the relative importance of the criteria. The scale of judging criteria is divided into 5 levels: extremely important, very important, relatively important and a little important, corresponding to the five scores: 9, 7, 5, 3 and 1. Similarly, the scale of comparing the alternatives also has 5 levels, corresponding to 9, 7, 5, 3, 1, which measures the degree of comparative advantage of each alternatives.

For example, the questionnaire pair-wise comparing the importance of the sub-criteria is as Table 2.

A	Scale									B
	9	7	5	3	1	3	5	7	9	
Completion										Correctness
Completion										Independency
Correctness										Independency

Table 2. Example of Questionnaire of criteria

Experts can check the appropriate box. If they think the value must be between 5 and 3, they can circle between the two boxes. Based on the responses in the questionnaire, we can construct the pair-wise comparison matrices, and calculate the weights of the criteria as well as the weights of the alternative level, which should be used as the value of x-axis and y-axis in Price's decision matrix. For the alternatives, check the consistency of the matrices and adjust the consistency if necessary.

4.3 Determine the value of x-axis and y-axis for Price's decision matrix and the levels of function allocation

Price's decision matrix is used in the process of determining the levels of function allocation. However the Price's decision matrix is a qualitative model, and we have to adjust this model to make it suitable for quantitative analysis. In this approach, we try to decide the value of x-axis and y-axis in the Price's decision matrix according to the weights of two alternatives calculated by AHP. Since the weights calculated by AHP is a value that between 0 and 1, we set 1 as the maximum value of x-axis and y-axis in Price's decision matrix, and set 0 as the minimum value of x-axis and y-axis. Based on the weights of two alternatives calculated by AHP, the value of x-axis and y-axis in the Price's decision matrix can be determined. That is, the weight of wholly allocating to human is used as the value of x-axis, and the weight of wholly allocating to machine is used as the value of y-axis.

In the six zones of Price's decision matrix, the performance of the functions in the bottom-left corner is unacceptable by both humans and machines, so the system should be redesigned to avoid this function (Price 1985). Therefore, except this area, the other five zones are all valid. Since the allocation scheme of these five valid areas described by Price is ambiguous, and the ten level of automation proposed by Parasuraman may not be entirely suitable for the function allocation of information systems, in accordance with the characteristics of information systems, the level of automation of information systems should be redesigned, corresponding to the five valid regions in Price's decision matrix.

Based on the ten levels of automation by Parasuraman, we combine some of the levels according to the characteristics of information systems, and design the five levels of function allocation, which is corresponding to each of the five valid areas in Price's decision matrix. The five levels of function allocation are shown in Table 3.

Region	Description
①	Information systems do everything, and show the execution results to users, and users could not affect the results.
②	Users input parameters related to the execution, then information systems execute according to the parameters and show the execution results to users.
③	Users input parameters related to the execution, then information systems execute according to the parameters and provides a series of alternatives for users to choose and adjust, and users make the final decision.
④	Information systems provide information to users for reference, and then users themselves make a series of alternatives, choose and adjust, until make the final decision.
⑤	Users do everything, and information systems offer no assistance.

Table 3. The five level of function allocation of information systems

After getting the value of x-axis and y-axis in the Price's decision matrix, the area where the function is would be determined. Then the level of function allocation can be found out, according to Table 3.

4.4 Decide the initial function allocation scheme and adjust it recursively

The initial function allocation scheme should be particularized in line with the level of function allocation and the specific requirement of information systems as well.

Table 4 shows an example of initial function allocation scheme, corresponding to the 5 valid areas in Price's decision matrix, which is the initial function allocation scheme of choosing reviewers for research projects of Beijing Municipal Science and Technology Committee.

Region	Description
①	Information systems choose reviewers from the database of experts automatically, and show the list of reviewers to users. Users could not change the reviewers chosen by the system.
②	Users input the restrictions concerning choosing reviewer, such as age, major and organization, etc. Then information systems choose reviewers from the database of experts according to the restrictions and show the list of reviewers to users. But user can not adjust the list showed by the system.
③	Users input the restrictions concerning choosing reviewer, such as age, major and organization, etc. Then information systems choose reviewers from the database of experts according to the restrictions and show the list of reviewers to users who can adjust the list and make the final decision.
④	Information systems print the list of all the alternative experts from the database and other restrictions as well. Users choose reviewers manually according to the list and the restrictions printed by the system. And input the chosen reviewers into the system manually.
⑤	Users choose reviewers manually, and information systems offer no assistance.

Table 4. Example of initial function allocation scheme

After getting the initial human-machine function allocation scheme, the prototype of information systems can be developed. Users can be invited to use the prototype under a practical scenario in order to evaluate the initial scheme. The feedbacks from the users are collected and the human-machine function allocation scheme can be adjusted recursively, until the satisfactory allocation solution is achieved.

5 AN ILLUSTRATION

In this section, we illustrate the proposed comprehensive approach by an example from developing an actual information system. This example is concerning the human-machine function allocation for choosing reviewers of research projects, which is one of the functions in the project management information systems of Beijing Municipal Science and Technology Committee.

5.1 Construct the hierarchy model

A hierarchy model was constructed first. As discussed above, the level of goal and alternative should be particularized according to the requirement of developing the information systems. According to the requirements of the project management information systems in Beijing Municipal Science and Technology Committee, the goal of the hierarchy model is that allocate functions between human and machine to increase the usability of the process of choosing reviewer. One of the two alternatives is choosing reviewers manually without the assistance of information systems, and the other alternative is choosing reviewers automatically without the intervention of users. The hierarchy model is shown in Figure 4.

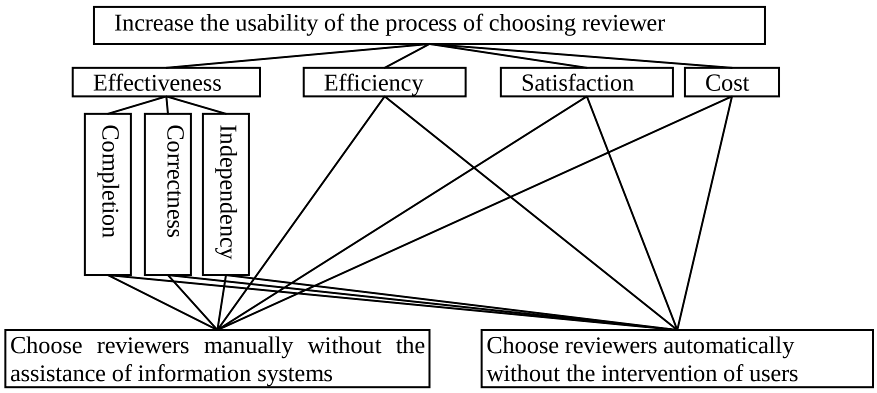

Figure 4. The hierarchy model of choosing reviewers

5.2 Send questionnaire, calculate pair-wise comparison matrices

A questionnaire was designed and sent to three experts in Beijing Municipal Science and Technology Committee, who were the users of the information system. These experts pair-wise compared the importance of the criteria in the criteria level, and at the same time pair-wise compared the advantages of the two alternatives. After collecting the questionnaire, we calculated the pair-wise comparison matrix respectively with a free software YAahp0.5.2 and checked for consistency. Due to space limit, here we only list the pair-wise comparison matrix from one of the three experts in Table 5, Table 6 and Table 7:

Overall Goal	Effectiveness	Efficiency	Satisfaction	Cost	Wi
Effectiveness	1.0000	5.0000	5.0000	6.0000	0.6144
Efficiency	0.2000	1.0000	3.0000	3.0000	0.2034
Satisfaction	0.2000	0.3333	1.0000	3.0000	0.1174
Cost	0.1667	0.3333	0.3333	1.0000	0.0648
The consistency: 0.0979; The weights to the overall goal: 1.0000					

Table 5. Pair-wise comparison matrix of criteria level

Effectiveness	Completion	Correctness	Independency	Wi
Completion	1.0000	1.0000	7.0000	0.4667
Correctness	1.0000	1.0000	7.0000	0.4667
Independency	0.1429	0.1429	1.0000	0.0667
The consistency: 0.0000; The weights to the overall goal: 0.6144				

Table 6. Pair-wise comparison matrix of sub-criteria level

Efficiency	Wholly allocate to human	Wholly allocate to machine	Wi
Wholly allocate to human	1.0000	0.1429	0.1250
Wholly allocate to machine	7.0000	1.0000	0.8750
The consistency: 0.0000; The weights to the overall goal: 0.2034			
Satisfaction	Wholly allocate to human	Wholly allocate to machine	Wi
Wholly allocate to human	1.0000	0.1429	0.1250
Wholly allocate to machine	7.0000	1.0000	0.8750
The consistency: 0.0000; The weights to the overall goal: 0.1174			
Cost	Wholly allocate to human	Wholly allocate to machine	Wi
Wholly allocate to human	1.0000	1.0000	0.5000
Wholly allocate to machine	1.0000	1.0000	0.5000
The consistency 0.0000; The weights to the overall goal: 0.0648			
Completion	Wholly allocate to human	Wholly allocate to machine	Wi
Wholly allocate to human	1.0000	3.0000	0.7500
Wholly allocate to machine	0.3333	1.0000	0.2500
The consistency: 0.0000; The weights to the overall goal: 0.2867			
Correctness	Wholly allocate to human	Wholly allocate to machine	Wi
Wholly allocate to human	1.0000	4.0000	0.8000
Wholly allocate to machine	0.2500	1.0000	0.2000
The consistency: 0.0000; The weights to the overall goal: 0.2867			
Independency	Wholly allocate to human	Wholly allocate to machine	Wi
Wholly allocate to human	1.0000	1.0000	0.5000
Wholly allocate to machine	1.0000	1.0000	0.5000
The consistency: 0.0000; The weights to the overall goal: 0.0410			

Table 7. Pair-wise comparison matrix of alternative level

After calculating the above pair-wise comparison matrix, we obtained the weights of the alternative level evaluated by this expert: the weight of "Wholly allocate to human" is 0.5374, and the weight of "Wholly allocate to human" is 0.4626. Correspondingly, we calculated the pair-wise comparison matrix of the other two experts. The weights of alternatives judged by three experts respectively are shown in Table 8.

Alternatives	Expert 1	Expert 2	Expert 3
Wholly allocate to human	0.5374	0.7095	0.5079
Wholly allocate to machine	0.4626	0.2905	0.4921

Table 8. The weights of alternatives to the overall goals by three experts

Calculating the weighted geometric mean of the results from the three experts, we yielded the overall weights of the alternative level judged by the three experts: the weight of "Wholly allocate to human" is 0.588, and the weight of "Wholly allocate to human" is 0.411.

5.3 Determine the value of x-axis and y-axis in the Price's decision matrix and the levels of function allocation

Based on the above results, the value of x-axis should be 0.588, and the value of the y-axis should be 0.411. With such values, we could draw a point in Price's decision matrix, as shown in Figure 5.

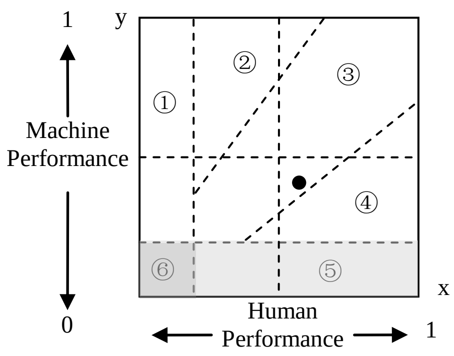

Figure 5. Price's decision matrix of the human-machine function allocation of choosing reviewers

Figure 5 shows that the point is in region 3. The corresponding level of function allocation is that users input parameters related to the execution, then the IS executes according to the parameters and provides a series of alternatives for users to choose and adjust, and users make the final decision.

5.4 Decide the initial function allocation scheme, and adjust it recursively in prototype

We could particularize the level of function allocation above, according to the specific requirement of Beijing Municipal Science and Technology Committee to find out the initial human-machine function allocation scheme. As the example in 4.4, the initial allocation scheme is as follows: users input the restrictions concerning choosing reviewer, such as age, major and organization, etc. Then information systems choose reviewers from the database of experts according to the restrictions and show the list of reviewers to users who can adjust the list and make the final decision.

A prototype of the IS was developed, including the initial human-machine function allocation scheme. The users from Beijing Municipal Science and Technology Committee were invited to use the prototype under a practical scenario in order to evaluate the initial scheme. The feedbacks of the users were collected and the initial function allocation scheme was adjusted correspondingly, until the satisfactory allocation solution of choosing reviewers was found.

6 CONCLUSION

In this paper, we reviewed existing methods and principles for human-machine function allocation. Then we proposed three guidelines: human and machine comparison, cost focus and human–centeredness. Under the three principles and combining both qualitative and quantitative methods, we developed a human-machine function allocation approach that suits information systems.

We then illustrated the approach with an example concerning choosing reviewers for research projects in the project management information systems of Beijing Municipal Science and Technology Committee. In the example, we only obtained data from three experts. In future practical use, we could send the questionnaires to more experts according to the actual requirements, making the group decision making process more reliable. In the example above, we calculated the pair-wise comparison matrix first and then collected results and calculate the weighted geometric mean of the results. Actually, we could also calculate the weighted arithmetic mean of the results from three experts. Moreover, we could also firstly calculate the arithmetic mean/geometric mean of each value in the pair-wise comparison matrix, and then calculate the weights of alternatives, so that we can also determine the function allocation scheme.

This study contributes directly to the human-centered systems development literature and practice. The three guidelines in this paper also are practically significant when try to determine the functions between human and information system. The comprehensive approach addresses the limitations of the existing allocation methods by building on their strengths. The step-by-step process makes it easy to use and manage, thus likely to yields high quality allocations. Besides a series of human-machine function allocation guidelines and a comprehensive approach, we also propose the five levels of function allocation and develop a system of criteria when designing the criteria level in the hierarchy model. These criteria can also be used in the evaluation of function allocation scheme. More work could be done to enrich and improve the five level systems and to evaluate the approach in real system development in the future.

Acknowledgement

This research was supported by National Natural Science Foundation of China under Grant 70971130, Beijing Natural Science Foundation under Grant 9112009, the Fundamental Research Funds for the Central Universities, and the Research Funds of Renmin University of China under Grant 10XNJ026, 10XNL014, 22392136. The second author is the corresponding author.

References

Butler. K.A. (1996). Usability engineering turns 10. *Interactions*, 3(1), 58-75

Cheng. E.W.L. and Li. H. (2001). Information priority-setting for better resource allocation using analytic hierarchy process(AHP). *Information Management & Computer Security*, 9(2), 61-70.

Common Industry Format for Usability Test Reports. Version 2.0, May 18, 2001

David. K.M. and Mak. (2006). *Task Coordination and Allocation Assistant*. University of British Columbia, Vancouver, Canada.

Dearden. A. and Harrison. M. and Wright. P. (2000). Allocation of Function: Scenarios, Context and the Economics of Effort. *International Journal of Human-Computer Studies*, 52 (2), 289-318.

DeLone. W.H, and McLean. E. (2003). The DeLone and McLean Model of Information systems Success: A Ten Year Update. *Journal of Management Information systems*, 19(4), 9-30.

Fitts. P.M. (1951). *Human Engineering for an Effective Air Navigation and Traffic Control System.* W Washington, DC: National Research Council.

Fitts. P.M. (1962). Function of Man in Complex Systems. *Aerospace Engineering*, 21(1), 34-39.

Iivari. J. and Iivari. N. (2011). Varieties of user-centredness: an analysis of four systems development methods, *Information Systems Journal*, 21(2), 125-153

ISO/DIS 9241-11 (1997). *Guidance on usability*.

Jordan. N. (1963). Allocation of functions between man and machines in automated systems. *Journal of Applied Psychology*, 47(3), 161-165.

Kantowitz. B. and Sorkin. R. (1987). *Allocation of functions*. In G. SALVENDY, Ed. Handbook of Human Factors, New York: Wiley, 365-369

Nielsen. J. (1993). *Usability Engineering*. New York: AP Professional.

Price. H.E. (1985). The Allocation of Functions in Systems. *Human Factors*, 27 (1), 33-45.

Parasuraman. R. and Sheridan. T. B. (2000). A Model for Types and Levels of Human Interaction with Automation. *IEEE Transactions on Systems, Man, and Cybernetics—Part A: Systems and Humans*, 30(3), 286-297.

Saaty. T.L. (1980). *The Analytic Hierarchy Process*. McGraw-Hil, New York, NY.

Sheridan. T.B. (2000). Function allocation: algorithm, alchemy or apostasy? *Human-Computer Studies*, 52(2), 203-216

Tang. Z. and Zhang A. Cao. L. (2008). Study on Man-Machine Function Allocation of Intelligent Fire and Command Control System. *Fire Control and Command Control*, 33(3), 39-43

Te'eni. D. and Carey. J. and Zhang. P. (2007). *Human-Computer Interaction: Developing Effective Organizational Information Systems*. John Wiley & Sons, Inc.

Wiener.N. (1988). *The Human Use Of Human Beings: Cybernetics And Society*. Da Capo Press.

Xu. D. and Zhu. X. and Yuan. Z. (2004). The Design Process of Human-machine System. *Journal of Machine Design*. 2004. 21(4): 11-13

Yang. H. and Zhu. X. and Li. D. and Guo. J. (2007). Research on function allocation of man- machine system. *Machinery Design & Manufacture*, 7, 151-153

Yi. H. and Song. B. and Ji. D. (2007). Research on Man-Machine Function Allocation of the Ground Control Station for Unmanned Aerial Vehicle of Scenario, *Fire Control and Command Control*, 32(12), 129-132

Zhang. P. and Carey. J. and Te'eni. D. and Tremaine. M. (2005). Incorporating HCI Development into SDLC: A Methodology. *Communications of the AIS (CAIS)*, 15(29), 512-543

Zhou. Q. and Zhou. S. (2003). Research on Model of Function Allocation between Human and Machine for Manned Spacecraft. *Chinese Journal of Ergonomics*, 9(2), 3-6