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Development of Cost Adjusted MIQ Concept for Measuring Intelligence Value of Systems

Tarik Ozkul and Ismail H. Genc

***Abstract*— Most systems that require the operator control can be considered as man-machine cooperative systems in whose functioning, humans, machines and other unintelligent parts play specific roles. Each role has a value. The recently developed machine intelligence quotient (MIQ) measures the contribution provided by the machines to a system. However, for a more practical decision making process, one needs to also consider the cost of improvements. We propose a simple measure cost-benefit criterion which enhances the aforementioned concept by adjusting it for cost, cost adjusted MIQ (CAMIQ). The method can be especially useful when trying to determine the best solution among several contenders which are similarly valued, but costwise different.**

***Index Terms*—Machine Intelligence Quotient, MIQ, Man-machine cooperative system, Human-machine cooperative systems, intelligent systems, cost of intelligence.**

I. Introduction

COST –benefit Analysis is an economics related concept typically used by decision makers to evaluate the desirability of a given intervention. This technique is ultimately used as a way of analyzing the cost effectiveness of different alternatives to see whether the benefits outweigh the costs. The purpose is to measure the efficiency of the added value with respect to the status quo. By evaluating cost-benefit ratio of different alternative approaches, one can determine which alternative solution provides the most benefit for the least cost [1]-[3]. Cost-benefit ratio of better solutions typically yield smaller ratio than competing alternatives. In economics related projects, costs and benefits of proposed additions are measured and evaluated in terms of monetary values. However, measurement of benefits in monetary terms is a difficult task which requires estimation of many of the involved parameters. Therefore, in real life it is not surprising to see the actual values deviate from the estimated ones by wide margins [4], [5].

Similar assessment difficulties may occur while adding value added features to man-machine cooperative systems. Man–machine cooperative systems typically comprised of a human controller, a computer controlled system and some additional non-intelligent parts.

A typical man-machine cooperative system is shown in Fig.1. The system functions as a whole with all parts working together. Human controller makes strategic choices; intelligent system executes the orders and generates subset of orders for non intelligent parts of the plant. Addition of a unit to the man-machine cooperative system involves cost of the added unit and the installation costs. Benefits of the added system appear as increase in performance, or reduction in complexity of the whole man-machine cooperative system which may be translated into some monetary terms. By determining the ratio of cost to benefit, one may assess the value of the addition.

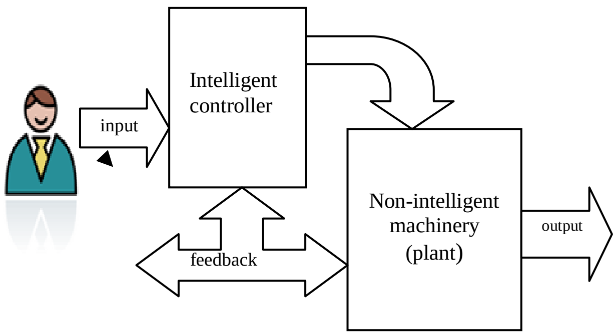

Fig.1 Typical man-machine cooperative system.

While adding value-added-features to a man-machine cooperative system, assessment of benefit can be a troublesome metric to measure. Measurement of this, in some cases, requires extensive estimation of parameters [4]. In such cases the recently defined term, namely machine intelligence quotient, MIQ, can be used as an alternative metric for measuring “benefit” part of the addition. Measurement of benefit in terms of Machine Intelligence Quotient (MIQ) yields an alternative way of measuring benefit. Thus MIQ can serve as a practical way of determining intelligence level of a man-machine cooperative systems setup. However, with the lack of attention paid on the cost side of this operation neglects a crucial economic measurement component in terms of cost-benefit analysis. MIQ, being an objective measurement parameter, can also be utilized to obtain an alternative path to determining the cost-benefit ratio of the set-up. In this paper, we intend to enhance the MIQ calculations with the cost adjustment to obtain a both technically and economically efficient system adjustment decision rule.

The rest of the paper is organized as follows: in the next section we describe the man-machine system, which is followed by a section devoted to the process of calculating the machine intelligence quotient. Then in Section IV we provide the definition of an adjusted MIQ to incorporate cost consideration, as well. In Section V, as a case study, we

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T. Ozkul is with the Department of Computer Science and Engineering, American University of Sharjah, Sharjah UAE. (phone: +971 6 515 2455; fax: +971 6 515 2979; e-mail: tozkul@aus.edu).
I. H. Genc is with the Department of Economics, American University of Sharjah, Sharjah UAE. (e-mail: igenc@aus.edu).

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attempt to determine the intelligence level of a robot controller setup and the cost of MIQ for it which is designed to do an adhesive dispensing operation. Later we add a vision guidance system to the setup and find the MIQ for the modified version and the cost of MIQ thereof. Section VI provides a comparative discussion on the two versions of the system. And Section VII concludes the paper.

II. Basic components of a man-machine cooperative system

Most general form of man-machine cooperative systems includes a human controller, an intelligent machine/controller, and many non-intelligent machine parts. In case of nuclear power plant, human controller is the person in charge of the control room monitoring and activating operation of the power plant, intelligent machine is a controller computer which monitors sensors, actuators and controls the process control loops. The plant contains many simple machinery parts like turbines, coolers and heaters which are considered the non-intelligent part of the man–machine cooperative systems. In case of a robot work cell, one can consider the human operator as a decision maker making selection about the type of the operation to execute, robot itself as the intelligent machine carrying out the processing and the feeder or conveyor belt as the non-intelligent part of the plant that works under the command of the intelligent parts of the system which is robot controller in this case. Examples can be increased further to extreme cases where human operator may or may not exist or cases where the non-intelligent machinery may or may not exist. In this paper, it is assumed that intelligent system is in the most general form which contains all three elements stated below;

- Human operator,
- Intelligent machine,
- Non-intelligent plant components.

With the operation of these three distinct parts, the system works and fulfills its purpose. The interaction between these three parts and the sequence of operations is described by intelligent task graph.

III. What is machine intelligence quotient?

Artificial intelligence and machine intelligence are two terms which are often used interchangeably. Artificial intelligence is widely regarded as the “science and engineering of designing intelligent machines”. Machine Intelligence Quotient, on the other hand is regarded by many as the parameter that reflects the “intelligence level of autonomous systems”. Machine intelligence has been a difficult concept to deal with and many researchers interpreted MIQ in different ways. Historically, Bien [6], [7] and Kim [8] were the first researchers who have defined MIQ as an indicator of machine intelligence. Lately, there were other researchers who have used MIQ concepts designed by Bien and Kim to determine MIQ of different set ups. Park et al [9], [10] used MIQ measurement to determine machine intelligence level of a nuclear power plant set up which is considered as a typical man-machine cooperative system which contained a human controller, intelligent automated controllers and dumb machines. Ulinwa [11] introduced some new interpretations to MIQ concept. Finally, Anthony and Jannett [12] used MIQ methodology to determine the intelligence level of a distributed network setup.

As far as the context of this paper goes, we will be adapting the definition of MIQ used by Park et al [9, 10]. According to this interpretation, systems or machines are not intelligent devices themselves. They are ultimately designed to assist a human operator who uses the system. MIQ is a parameter which reflects the ease of use of the system by the operator. Systems which are easy to use by the operator have high MIQ which reflects this ease of use. Systems which are found difficult to use by the operator have low MIQ which reflects the difficulty. In this context, all existing systems which are designed to be used by human operators have an MIQ of some sort.

Consider the following example of a household heating system to describe the concept. Imagine an old heating unit where the operator needs to light the pilot lamp, turn the gas valve, open and close several water valves and intervene frequently to keep the temperature at a comfortable level. Now picture a new unit where the operator sets the temperature level and simply pushes a button to activate the system. In both cases the systems are actually doing exactly the same thing, but in the case of the latter, the unit, i.e., the machine, is doing many of the steps like turning valves, lighting the pilot etc on its own. It is assumed that keeping a house warm at a comfortable level requires certain amount of work (intelligence). This work is partly being done by the operator and partly by the heating system itself. In the case of former unit which requires much intervention from the operator, operator spends considerable effort to keep the house warm at a specific temperature level. In the case of the second system, the operator effort is much less to achieve the desired heating quality. In terms of MIQ, we say that first system has low MIQ because many actions need to be done by the operator. In contrast, the second system has high MIQ since operator spends very little effort to achieve the desirable heating performance. The rest of the actions are being done by the heating system itself.

As one would notice, according to this version of understanding, the concept of MIQ does not really require the system to have a processor or built in intelligence inside. It assesses MIQ by the end value it provides toward achieving a certain goal. Accordingly any system, regardless whether there is a processor inside or not, has some MIQ which can be quantitatively measured. The concept is illustrated in Fig. 2.

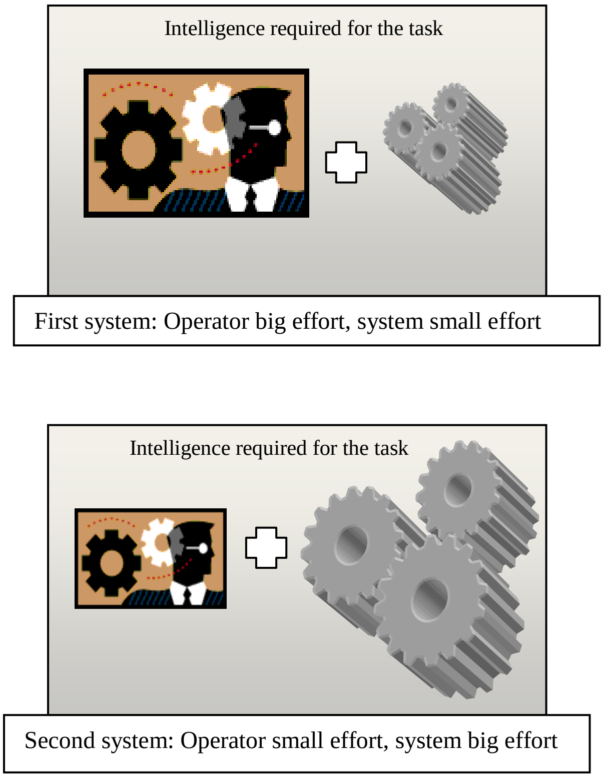

Fig. 2 Two identical systems doing the same job with different MIQ's. Gear size represent the MIQ of the system operator is dealing with.

A. *Intelligence task graph*

An intelligence task graph is a state diagram of operation which describes all the stages of the process the system has to go through from the beginning until the completion of the task. The intelligence task graph (ITG) also indicates which tasks are being executed by which part of the intelligent system. The tasks which are done by the human operator, the tasks which are done by the intelligent controller and the tasks which are performed by non-intelligent plant components are all displayed by the ITG graph.

ITG graph specifies processes by the use of bubbles and directed arrows. Bubbles show processes, and arrows identify the sequence and flow of information from one process to another. Following the terminology developed by Park et. al. [9], T indicates the set of tasks or processes to be completed where T is a vector with n components.

The task set is defined as;

$$\mathbf{T} = \{T1, T2, T3, \ldots .Tn\} \qquad (1)$$

The task intelligence cost is a subjective parameter that indicates the difficulty of a specific task. This parameter is estimated by the user and it is denoted by τ.

$$\boldsymbol{\tau} = \{\tau 1, \tau 2, \tau 3, \ldots .\tau n\} \qquad (2)$$

The data transfer matrix **F** defines the amount of information transferred from one task Ti to another task Tj.

$$\mathbf{F} = \begin{bmatrix} 0 & f12 & f13 & f14 & . & . & f1n \\ f21 & 0 & f23 & f24 & . & . & f2n \\ f31 & f32 & 0 & f34 & . & . & f3n \\ f41 & f42 & f43 & 0 & . & . & f4n \\ f51 & f52 & f53 & f54 & 0 & . & f5n \\ f61 & f62 & f63 & f64 & f65 & 0 & f6n \\ fn1 & fn2 & fn3 & fn4 & fn5 & . & 0 \end{bmatrix} \qquad (3)$$

Another matrix used in the intelligence task graph is the Task Allocation Matrix which defines which tasks are executed by which part of the system. The task allocation matrix is represented by **A.** By definition, the number of columns in matrix A is restricted to 3, where the first column indicates the tasks assigned to the intelligent machine controller, the second column indicates the tasks which are assigned to human controller, and the third column indicates the tasks which are executed by the non-intelligent part of the plant. Matrix **A** is a binary matrix with values of either 1 or 0.

$$A = \begin{bmatrix} a11 & a12 & a13 \\ a21 & a22 & a23 \\ a31 & a32 & a33 \\ . & . & . \\ . & . & . \\ . & . & . \\ an1 & an2 & an3 \end{bmatrix} \qquad (4)$$

In the above matrix, if task 1 is executed by the intelligent controller part of the system, a11=1 and a12=a13=0. If task 2 is executed by the human controller, than a22=1 and a21=a23=0. With this consideration matrix has binary entries which consist of 1's and 0's.

B. *Control Intelligence Quotient*

The Control Intelligence Quotient (CIQ) is defined as the total intelligence required for carrying out all the tasks in the man–machine cooperative system. The formula that describes CIQ is as follows;

$$\mathrm{CIQ} = \sum_{i=1}^{n} ai1.\tau i + \sum_{i=1}^{n} ai2.\tau i \qquad (5)$$

which is the combination of the intelligence of the intelligent controller and the intelligence of the human controller together.

Putting it in a different way, Control intelligence quotient CIQ of the system is a combination of the intelligence contributed by the human controller and the intelligence provided by the machine.

$$\mathrm{CIQ} = \mathrm{HIQ} + \mathrm{MIQ} \qquad (6)$$

Using the aforementioned household heater example, the job of heating the house and keeping it at a comfortable set

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temperature is a job which requires certain amount of intelligence, which is indicated as CIQ in the formula. This task is being done by the cooperation of human controller and the machine. The contribution of human controller to the completion of the task CIQ is labeled as HIQ, and contribution of the machine controller toward this goal is represented by MIQ. In other terms, addition of HIQ and MIQ is a set number for a certain given task. Thus, for a given specific task, if the human operator involvement increases (high HIQ), the machine part involvement (low MIQ) decreases. Decreasing human involvement means (less HIQ), which ultimately points to a system with high machine intelligence (high MIQ).

C. Human Intelligence quotient

Human intelligence quotient (HIQ) is defined as the intelligence quantity needed from the human controller for controlling the system. The formula for HIQ is given as follows:

$$\mathrm{HIQ}=\sum_{i=1}^{n} ai2.\tau i \; + Cmh \sum_{i=1}^{n}\sum_{i=1}^{n} ai1.aj2.fij + Chm \sum_{i=1}^{n}\sum_{i=1}^{n} ai2.aj1.fij \tag{7}$$

The first summation term indicates the combination of all tasks done by the human controller multiplied by difficulty levels of tasks. Second term in the formula includes a multiplicand parameter Cmh, which is defined as the interface complexity, which describes the difficulty of transferring data from machine to human. Through this second term we include all the intelligence demanded from human controller for interpreting information that comes from machine to human. The third summation term uses a parameter labeled as Chm which is defined as the interface complexity while transferring data from the human controller to the machine controller. Chm and Cmh are two indexes which are decided subjectively to indicate the difficulty level. These parameters vary between 0 and 1, 0 being the easiest and 1 being the hardest in assessing the difficulty of entering or interpreting data. Typically difficulty levels of these parameters are expected to be around 0.05 for well designed systems which more or less corresponds to the difficulty of pressing a single button to initiate a process.

D. MIQ, HIQ and CIQ relationship

MIQ is defined as the difference between CIQ and HIQ.

$$\mathrm{MIQ}= \mathrm{CIQ} - \mathrm{HIQ} \tag{8}$$

The rationale behind this definition is as follows; CIQ is the total amount of intelligence required to run the system which is partly contributed by human controller and partly contributed by intelligent machine controller. MIQ, which is the true intelligence due to machine intelligence is supposed to be found by taking away the contribution done by the intelligence of human controller (HIQ).

IV. DERIVATION OF THE COST ADJUSTED MIQ

In this section, we would like to enhance the definition of MIQ to also incorporate a consideration of the cost in system adjustments. MIQ can be used as factor in cost-benefit analyses when determining the value of man-machine cooperative systems [13]. That would make MIQ more appealing to decision makers in business world as it reflects both the cost and benefit of undertaking a system adjustment. We assume that the decision maker assigns a subjective pecuniary value to each unit of MIQ, yielding MIQm, which is the monetary value of the intelligence of the machine as perceived by the decision maker. Then, when MIQm is used for benefit measurement, the division of the cost involved by the MIQm of the system reveals a parameter which determines what could be construed as the cost-per-MIQ. Naturally, the perception of intelligence is a subjective matter, and its identification in financial terms varies from person to person. Therefore, MIQm reflects that personal view of decision makers in system MIQ assessments. Thus, the cost-per-MIQ, K, is calculated according to the following formula.

$$\mathrm{K} = \frac{\mathrm{C}}{\mathrm{MIQm}} \tag{9}$$

where C stands for the cost of the system. Among the two competing solutions, if alternative #1 approach reveals K1 and alternative #2 reveals K2; and, if among the alternative solutions K1<K2, it can be said that alternative #1 is a better solution which provides better MIQ per capital. One might call K the Cost Adjusted MIQ, CAMIQ. Obviously, CAMIQ may be utilized in comparing a number of systems and/or upgrades to an existent system.

Through CAMIQ, that is, by measuring the cost-per-MIQ of different alternatives, one may decide which alternative solution may present the most MIQ per capital spending. The advantage of using MIQ as an objective benefit measurement tool is such that, it provides a unique way of assessing the impact of addition (upgrade) in terms of increase in intelligence. Since MIQm reveals the decision maker’s perception of this addition, CAMIQ provides a further tool in consideration of system upgrades and/or comparisons. Therefore, gauging MIQ against the cost in the form of CAMIQ enhances the usability of MIQ in decision making processes in practice. Nevertheless, a researcher should always keep in mind that measurement of benefits in monetary terms is a difficult task which requires estimation of many of the involved parameters (see [4] and [5] for a discussion on the issue in empirical projects).

One of the most fundamental questions for decision makers, however, is to determine the amount/level of cost to tolerate in conjunction with the improvements in the system where the latter is measured by MIQm. In other words, what is the optimum decision making rule for the cost-benefit issue discussed in this paper? The answer to this question is easily derived by taking the total differentiation of equation

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(9), and equating to zero for an optimization problem. That is,

$$d(K) = d(C) - d(MIQm) = 0 \tag{10}$$

Hence, it is easy to observe that

$$d(C) = d(MIQm) \tag{11a}$$

and by approximation

$$\Delta(C) = \Delta(MIQm) \tag{11b}$$

which has a familiar economic interpretation. The left hand side of the equation above represents the marginal cost of an economic activity while the right hand side characterizes the marginal benefit thereof. By following the economic logic, one can say that a decision maker will continue upgrading a particular system for as long as the additional benefit of this operation is no less than the additional cost of this operation involved. As the economic theory goes, then, the decisions are made on an incremental basis comparing the cost and benefit of every action, which is what our cost adjusted MIQ, viz. CAMIQ, definition finds.

V. CONCLUSIONS

The determination of the cost of the MIQ improvements of the man-machine cooperative system provides a metric which indicates the intelligence cost of a system. In this paper, we develop a simple measure of the cost of such improvements, which we call CAMIQ, the cost adjusted machine intelligence quotient. This straightforward extension of the newly developing field of machine intelligence measurements brings the engineering concepts more in line with their counterparts in economics and business, hence making them more relevant for practical considerations.

The information provided by CAMIQ is not intended to be a replacement for all cost-benefit analyses; rather it should be used as complementary to any cost-benefit calculations with different deliberations in mind. The CAMIQ parameter inherently contains information about the ease of use of the system. Therefore, it can be especially useful when determining the suitability of several competing solutions. As an example, suppose we are asked to calculate whether it is a good idea to add visual guidance to a robot arm. Suppose the calculations have indicated that the CAMIQ of the robot system in our experiment has been improved by the addition of the visual guidance system. Based on this finding, as CAMIQ calculations take into consideration both the cost of the additional hardware and the MIQ increase of the setup, we can safely claim that it is beneficial to install the visual guidance setup.

Obviously the cost of the guidance system has a lot to do with the CAMIQ value. As the cost of the visual guidance setup goes up, the CAMIQ calculation would increase and eventually give the exact same CAMIQ as the plain setup without the visual guidance. That would indicate a neutral cost change which may have hinted that adding a visual guidance system may not be a worthwhile decision.

One can rightfully argue that while calculating the CAMIQ, the cost of the system is not only the material cost but it should also include costs like installation, training etc. Normally the cost calculations should include all these factors.

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