VOLUME 9, ISSUE 1, 2014

ISSN 2045-3345

ON THE ESSENCE OF HARDWARE PERFORMANCE

Vladimir Sulov[I]
University of Economics, Varna, Bulgaria

ABSTRACT

The computerization and adoption of information technology are key factors in the economy and society of the 21st century. The widespread usage of computer systems and networks, software and services leads to an increased spending on information and communications technology, which reaches almost 4 trillion US dollars annually. The spending is done both by business organizations and ordinary home users and is of such number that demands a theory and methodology for assessing its value and efficiency. Thus the purpose of this paper is to study the essence of computer hardware performance in the light of the ever-increasing user needs and to develop a methodology for assessing its value. Hardware performance is considered as an economic equivalent of its value and revenue. Based on the observation and data that users' needs increase in time, hardware performance is also examined dynamically and in perspective. As needs increase exponentially, it is not a trivial task to assess needs in time. As needs increase, relative performance of the used hardware decreases. Therefore a mathematical system for measuring the different types of performance is proposed. Using this methodology business and ordinary users can analyse their future needs and compare them to the expected hardware performance. The results of applying the proposed system could lead to better business spending policies and an increased efficiency of expenditures on hardware.

JEL CLASSIFICATION & KEYWORDS

■ C8 ■ L86 ■ M15 ■ HARDWARE PERFORMANCE ■ INCREASING NEEDS ■ HARDWARE EFFICIENCY

INTRODUCTION

The development of contemporary economy that began with the industrial revolution today is characterized by high levels of consumption, globalization with an increasing trans border exchange of goods, services, and capital, strong competition and dependency on technological innovation and comparative advantages.

The computerization and adoption of information technology (IT) are key factors in the economy and society of the 21st century. The widespread usage of computer systems and networks, software and services leads to an increased spending on information and communications technology (ICT), which reaches almost 4 trillion US dollars annually. The spending is done both by business organizations and ordinary home users and is of such number that demands a theory and methodology for assessing its value and efficiency.

The purpose of this paper is to study the essence of hardware performance in the light of the ever-increasing user needs and to develop a methodology for assessing its value. A unified ICT-efficiency theory is beyond our scope, as we will concentrate primarily on computer hardware.

The Increase of ICT Spending

Today economic activity and even everyday life is unthinkable without information and communications technology. Hardware capabilities are increasing, as is network bandwidth. New devices and technologies are emerging. System software is moving ahead with robust, network, multi-tasking, multi-user operating systems with friendly user interfaces. Application software has reached new levels of ease-of-use and features and does not require any specific skills or programming. All of these advances in the IT sphere have lead to an increased value and necessity of technology adoption both in organizations of all kinds, and at home.

Undoubtedly one of the driving forces behind economy and society is the Internet. In 2012 Internet users were 34% of the world population (Internet World Stats, 2013). For comparison, in 2000 they were only 5.9% or they have increased almost 6 times. At the same time the world population constantly grows which means that in absolute numbers the Internet users are growing even more. In 2000 the Internet users were 361 million, and in 2012 they were already 2.4 billion which represents a 7 times increase. Internet access is facilitated by the general availability of computers at home. 27.3% of the population, or 34% of the households worldwide have an access to a computer at home (International Telecommunication Union, 2010). The value of global semiconductor sales (as semiconductors are fundamental to all computer and communications equipment) grew 4 times from approx. $50 billion in 1990 to $213 billion in 2004 with an average annual rate of 11%. In 2011 the semiconductor sales reach a record $300 billion with an annual rate after 2004 of approx. 7% (see Table 1).

Table 1: Global Semiconductor Sales

Year	1976	1981	1986	1991	1996	2001	2006	2011
Sales (billion US$)	3	9	26	54	134	147	246	300

Source: Semiconductor Industry Association (SIA) (2013)

The global ICT spending reached US$ 2.3 trillion in 2003 with a 10% annual growth (see Table 2). In 2004-2010 it was also rising with a minor decrease only in 2009 but reached a new record value of US$ 3.8 trillion in 2010.

Table 2: Global ICT Spending

Year	1976	1981	1986	1991	1996	2001	2006	2011
Sales (billion US$)	3	9	26	54	134	147	246	300

Source: World Information Technology and Services Alliance (2004) and (2010)

[I] vsulov@ue-varna.bg

ISSN 2045-3345
RESEARCH JOURNAL OF ECONOMICS, BUSINESS AND ICT

Forecasts clearly show that spending will continue to grow, as will trade and investments.

If we analyse the presented data we can find that for the last 35 years there is a clear trend of increasing spending on semiconductors and ICT. The spending not only grows in absolute value but also as a significant part of world's production. In 2010 the ICT spending was equal to 6% of world's total gross domestic product (International Monetary Fund, 2012). In turn that means that 6% of the production of every inhabitant of the Earth is spent on ICT, which is a really high number.

Business and home buyers are able to measure their ICT spending and costs in each case. ICT costs are not only initial and direct (for example when buying a computer system) but also future and indirect. In this respect, back in 1987 TCO (Total Cost of Ownership) theories became popular. According to Gartner (2013), TCO is a "comprehensive assessment of information technology (IT) or other costs across enterprise boundaries over time. For IT, TCO includes hardware and software acquisition, management and support, communications, end-user expenses and the opportunity cost of downtime, training and other productivity losses."

Looking at annual ICT spending of US$ 3.8 trillion we find the existence of a theory for assessing their value imperative. Both business organizations and ordinary ICT buyers need serious and formalized tools for analysing their choice and purchases. In a highly competitive environment, instability and economic risk, the possibility of improving ICT spending efficiency could be a key factor for success.

On Assessing the Value of ICT

As we noted ICT costs can be measured but it is not clear how to quantitatively measure their revenue and value in absolute and relative terms. We think that such measurement cannot be done in monetary terms because of several reasons:

- There is no direct relation between ICT costs and the quantity of "work" they provide in the production process.
- The output and revenues of companies can be measured but it is impossible to directly and mathematically correlate them to the ICT input (costs).
- Ordinary home users and households do a lot of the spending so there could be no economic profit measured but still they also should have a way of assessing the efficiency of their purchases.

It is our opinion that performance should be the measure of the value and revenue from ICT. We will use "computer system performance" as a general term meaning the ability of a computer system with its hardware and software configuration to perform specific tasks (i.e. Video processing, backup and storage, act as web servers, DBMSs, etc.). Often the term "speed" is used in a similar way. We prefer "performance" because some of the parameters (for example the amount of memory and not its speed) also affect performance. In reality, especially concerning the hardware, which we will focus on, its value is indeed most directly connected to its speed. Although our definition emphasizes speed and quality when performing specific tasks, more generally speaking, it means whether these tasks could be performed at all. For example the size of a hard drive may not affect speed but if it were below a certain minimum, the intended tasks would not be possible at all.

Measuring Hardware Performance

As we noted, concerning the hardware, its performance and value are typically identified with its speed. The multitude of makes, models and parameters of hardware components makes it impossible to compare them just by their specifications. For example it is impossible to judge the performance of an Intel Core 2 Duo 3.33 GHz CPU against an AMD Phenom II X2 3.1 GHz CPU purely by looking at their specs. On the other hand, performance cannot be judged independently of the tasks that would be performed, for example a CPU could be better in integer or floating operations, parallelism, etc.

These considerations have led to the creation of highly specialized tests (or "benchmarks") of the most important hardware components as CPUs, hard drives, graphic chips. The results of such tests are numerical values in self-defined (and usually equalling the name of the respective test) units. We can classify hardware tests by 2 characteristic features: whether they test a specific component or an entire system, and whether they measure general or specific-task performance. Only a specific component can be tested (for example the CPU) or the performance of an entire computer system. Testing an entire computer system can also vary by including a different set of components and relative weighs. General performance tests show an average and non-targeted assessment of the performance of a component or a system, while specific-task tests assess how a system would behave doing video processing, office apps, games, etc. Combining the two categories we get 4 types of tests:

- Specific component general performance tests.
- Entire system general performance tests.
- Specific components specific-task tests.
- Entire system specific-task tests.

Specific component general performance tests are Whetstone, Dhrystone, SPEC CPU, CoreMark, LINPACK, etc. Most often the tested component is the CPU. Entire system general performance tests differ to some extent depending on the components included in the test (besides the CPU). Some include the memory, disk and graphics systems, and others. Such tests are GeekBench, SYSmark, PassMark. Specific components specific-task tests are rarely used and usually test only the CPU. Such tests are for example DENBench, which tests the CPU for multimedia tasks, AutoBench for the automotive industry and others. Entire system specific-task tests are the most common and numerous because usually computer systems are bought for specific and known at the time of purchase tasks. Thus it is valuable for the buyers (users) to be able to assess the machine's performance concerning its future use, incl. software. Such tests are the suite of TPC (Transaction Processing Council – TPC-C, TPC-E, TPC-H), Cinebench, SPEC, etc. There are even tests that measure home system performance for multimedia, games like WoW (World of Warcraft), Quake/Doom, etc.

We can conclude that the necessary means for measuring hardware performance exist – both in terms of different users (home and business ones), spheres of application (office suites, video processing, CAD/CAM, Dbs, e-business, etc.), different roles (workstations and servers).

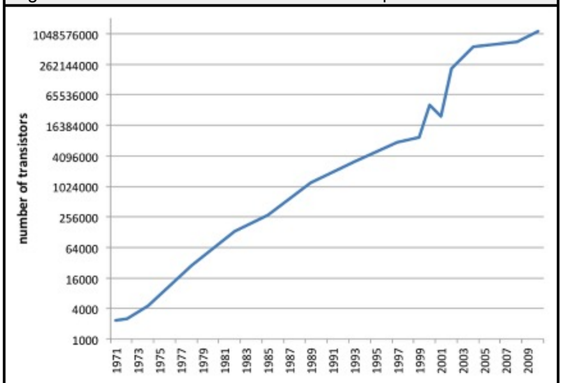
Hardware Performance Increase Rates

Considering the fact that hardware performance can be measured, the users (buyers) can assess their target computer systems in relation to their current needs.

The basic problem is that reality has shown that not only the performance of new hardware but also the needs grow exponentially in time. Therefore it is necessary when making computer hardware buying decisions, to analyse not only the current needs and expected performance but also the future ones.

The increasing rate of computer capabilities was observed even in the dawn of this technology. Gordon Moore (1965), co-founder of Intel, made a statement which later became known as the "Moore's law" and noted that the number of components per integrated circuit doubles every 2 years. The observation was made in the period 1958-1965 and Moore believed it would remain "nearly constant for at least ten years". Figure 1 shows the number of transistors in Intel's processors for the period 1971-2010. The vertical axis is logarithmic as the rate of increase is exponential. The horizontal axis is temporal.

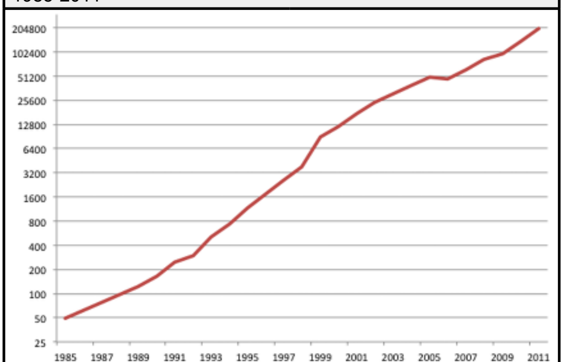
Figure 1: The number of transistors in Intel's processors



Source: Wikipedia (2013a)

Moore's and later data shows that his prediction is valid for more than 45 years now and most researchers agree that it will be valid for another 5-10 years in its current form (Kanellos, 2005) or possibly even more with minor rate adjustments. Hardware design and the law itself will probably reach some limitations but for our purposes it is important that there is a connected exponential and unlimited increase in CPU and hardware performance. We already looked at the possible options how to measure hardware performance and the multitude of existing tests. Using historical data for CPU (as the leading element in a computer system) performance we can reveal the trends. A methodology previously developed by us and gathered data (Sulov, 2012) allow us to calculate unified performance results for the most common CPUs in the last 25-30 years. This data is graphically interpreted in Figure 2 where the vertical axis is also logarithmic.

Figure 2: Unified performance results for typical CPUs in the period 1985-2011



Source: Author

The increase rate, although a bit fluctuating, is clearly stable and exponential. For better precision we will calculate the time interval (in years) in which the performance doubles. In honour of Gordon Moore, we will call this value "Moore's quotient" and mark it with MQ. The calculation of the value based on empirical historical data can be done through the following equation:

$$P_a 2^{\frac{Y}{MQ}} = P_b \quad (1)$$

where:

P_a is the performance at the start of the period,

P_b is the performance at the end of the period,

Y is the length of the period (in years),

MQ is Moore's quotient (in years), i.e. the sought value in this case.

We can read the equation as this: the initial performance P_a doubles Y/MQ times in order to reach the final performance P_b.

The equation (1) can be transformed as:

$$2^{\frac{Y}{MQ}} = \frac{P_b}{P_a} \quad (2)$$

In order to solve it for MQ we apply a base 2 logarithm to both sides:

$$\log_2 2^{\frac{Y}{MQ}} = \log_2 \frac{P_b}{P_a} \quad (3)$$

After simplifying:

$$\frac{Y}{MQ} = \log_2 \frac{P_b}{P_a} \quad (4)$$

Thus:

$$MQ = \frac{Y}{\log_2 \frac{P_b}{P_a}} \quad (5)$$

Our unified data for the last 25 years (Sulov, 2012) allows us to calculate more precisely Moore's quotient. Applying the formula we find that MQ = 2.17. In other words, for the last 25 years (1985-2011), hardware performance (based on CPUs) doubled every 2.17 years (approx. every 2 year and 2 months). As Figure 2 shows the rate is stable and gives us ground to conclude that it will be sustained at least in the short term and even if it does change a bit, the Moore's quotient can easily be adjusted and re-calculated.

The exponential increase of hardware performance is obvious. At the same time, though, a lot of other factors concerning computer usage are changing, which affect the actual performance that users get. During the last 25 years lots of changes occurred in system software, which influenced application software too. Operating systems evolved from a text-based to a graphical user interface with network, multi-user and multitasking capabilities and include more and more features and components. The source code (in number of lines) of Windows has increased 10 times for a period of 10 years (Maraia, 2005). The increased capabilities of operating systems require more powerful hardware. If we apply our formula (5) to the minimum Windows requirements in 1996 and in 2009 (Wikipedia, 2013b) for the CPU we find MQ = 1.9. That means that for the period the minimum requirements towards CPU performance have doubled every 1.9 years. Applying the same formula for the memory requirements we get MQ = 2.0, that is every two years memory needs doubled. The results demonstrate that performance needs increase at the same time as performance itself and also at a similar exponential rate. The great number of activities, which require computer power and the increased number of different tasks that most of the typical users perform, also determine the growth of needs. New fields of research and application are emerging such as genetics, 3D modelling, film industry, etc., where requirements are even greater. The world volume of data increases which makes it difficult to extract and process relevant information. The data is global, unstructured, in different languages, from different types of sources like text, audio, video.

Types of Hardware Performance

The analysed data undoubtedly illustrates that hardware needs increase exponentially. It is beyond our scope to find the exact reasons for that and whether performance creates needs or vice-versa. Still, the most important conclusion we can make is that hardware performance should be considered dynamically and in perspective and any performance and needs assessment should be conducted not only concerning a certain present moment in time but also the future. This necessity can be illustrated by a simple example. Let's presume that a computer system with a specific configuration outperforms the current needs 2 times. Our observation that needs double in 2 years means that after 2 years the same system would still cover the needs but at a minimum level. In 4 years the computer system will be 2 times less productive than the needs. We find it necessary to create a mathematical model that can assess the future performance of hardware based on its current performance and the increasing needs. From a practical viewpoint such a model could be used when buying computer hardware.

We will define several types of performance:

- Absolute performance.
- Minimum performance.
- Initial performance.
- Relative performance.
- Average performance.
- Total performance.

Absolute performance is the performance of a system or a component measured in absolute numbers using a specific test. It can be for example the Cinebench result of a system that will be used for video processing. As we noted, there are lots of hardware performance tests, which give a precise idea about the speed of different components or entire systems for different purposes. The general availability of test results means that computer hardware can be assessed before making purchases, i.e. absolute performance is known.

It is quite logical that before purchasing hardware the current needs should be assessed. Although a methodology for such an assessment is beyond the scope of this paper, the operating system's and software applications' requirements should be taken in consideration, as other relevant factors. Minimum performance is the speed that meets the minimum requirements at a current moment of time. Obviously the choice of a system and/or components will be only among such that have an absolute performance higher than the minimum one.

We will call the absolute performance of a system/component at the moment of purchase initial performance. Thus initial performance will also be higher than minimum performance.

Absolute performance does not change with time but because of the increasing needs its actual value is declining. We will define relative performance, which will reflect the actual performance that a component/system yields after a specific period of time. For example using an increasing needs quotient MQ = 2, in 2 years time a computer system will have 2 times lower relative performance than the initial one. After 6 years, the same system will have 8 times lower relative performance.

As we noted, usually the single most important requirement about performance is that it should cover the minimum needs and it is so in the beginning. But as needs increase, the requirement can be paraphrased that it is necessary for the relative performance to be higher than the minimum one. Therefore we should be able to calculate relative performance. The decrease is exponential, similar to (1):

$$P_r = \frac{P_i}{2^{\frac{Y}{MQ}}} \tag{6}$$

where:

P_i is the initial absolute performance,

P_r is the relative performance after Y years,

MQ is Moore's quotient (in years).

In (1) the sought value was MQ, while in (6) we use the empirically found value of MQ concerning needs. Moore's quotient can be calculated more precisely if any changes in needs rates occur. Using the formula we can calculate the relative performance after Y years and whether it will be still above the minimum one. In that sense it will me more valuable to calculate the period after which the relative performance will equal the minimum performance, i.e. the "life" of computer hardware. Using P_b for the minimum needed performance we can substitute:

$$P_b = \frac{P_i}{2^{\frac{Y}{MQ}}} \tag{7}$$

and solve the equation for Y. Transforming:

$$2^{\frac{Y}{MQ}} = \frac{P_i}{P_b} \tag{8}$$

We apply a base 2 logarithm to both sides:

$$\log_2 2^{\frac{Y}{MQ}} = \log_2 \frac{P_i}{P_b} \tag{9}$$

Simplifying:

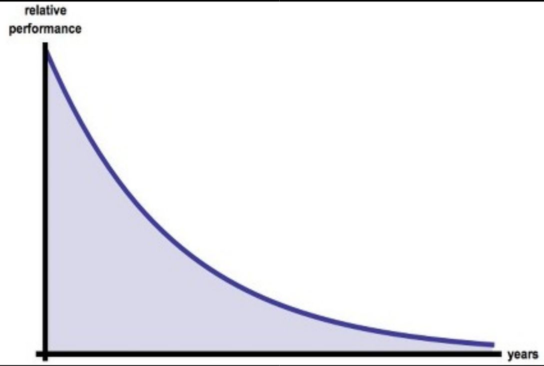
$$\frac{Y}{MQ} = \log_2 \frac{P_i}{P_b} \tag{10}$$

Thus:

$$Y = MQ \log_2 \frac{P_i}{P_b} \tag{11}$$

Using the formula (11) we can calculate how many years after the purchase a computer system will still meet the minimum requirements. At the same time, the value of a computer system cannot be expressed solely by the time that it is above a minimum level. The efficiency will be higher when there's a higher average performance. We will define average performance as the average relative performance that a given computer system/component yield during a specific period of time. As the needs increase exponentially and relative performance decreases exponentially, the average performance does not equal the initial + final ones divided by two (which would be the case if the increase of needs / decrease of relative performance were linear). We already showed how relative performance could be calculated (6). The graphical interpretation of average performance is shown in Figure 3.

Figure 3: Graphical interpretation of relative performance



Source: Author

In order to calculate average performance we will find the total performance – the sum of the relative performance for the period and divide it by the length of the period. The total performance on the chart is the coloured area. To calculate it we can use the following definite integral:

$$P_t = \int_0^Y P_r dx \quad (12)$$

where

P_t is total performance,

P_r is relative performance after Y years.

We substitute, using (6):

$$P_t = \int_0^Y \frac{P_i}{2^{\frac{x}{MQ}}} dx \quad (13)$$

where:

P_i is the initial absolute performance,

x is the time interval, which can vary from 0 (zero, the initial time of measuring / purchasing) to Y (the end of the period for which we are trying to find the average performance).

In order to solve the definite integral we will solve the respective indefinite integral:

$$\int \frac{P_i}{2^{\frac{x}{MQ}}} dx \quad (14)$$

Transforming:

$$\int \frac{P_i}{2^{\frac{x}{MQ}}} dx = P_i \int \frac{1}{2^{\frac{x}{MQ}}} dx \quad (15)$$

Transforming:

$$\int \frac{P_i}{2^{\frac{x}{MQ}}} dx = P_i \int 2^{-\frac{x}{MQ}} dx \quad (16)$$

Transforming:

$$\int \frac{P_i}{2^{\frac{x}{MQ}}} dx = P_i \int (2^{-\frac{1}{MQ}})^x dx \quad (17)$$

Thus (Spiegel, 1998):

$$\int \frac{P_i}{2^{\frac{x}{MQ}}} dx = P_i \frac{e^{x \ln(2^{-\frac{1}{MQ}})}}{\ln 2^{-\frac{1}{MQ}}} \quad (18)$$

Transforming:

$$\int \frac{P_i}{2^{\frac{x}{MQ}}} dx = \frac{P_i 2^{-\frac{x}{MQ}}}{-\frac{1}{MQ}\ln 2} \quad (19)$$

Or:

$$\int \frac{P_i}{2^{\frac{x}{MQ}}} dx = \frac{-MQ.P_i 2^{-\frac{x}{MQ}}}{\ln 2} \quad (20)$$

The resulting formula (20) is the indefinite integral or the so-called anti-differential of the function of the sought value of the definite integral of average performance or the so called by us total performance. If we mark (20) with F(x), than:

$$P_t = \int_0^Y \frac{P_i}{2^{\frac{x}{MQ}}} dx = F(Y) - F(0) \quad (21)$$

or substituting with the result for F(x):

$$P_t = \frac{-MQ.P_i 2^{-\frac{Y}{MQ}}}{\ln 2} - \frac{-MQ.P_i 2^{-\frac{0}{MQ}}}{\ln 2} \quad (22)$$

Simplifying:

$$P_t = \frac{-MQ.P_i 2^{-\frac{Y}{MQ}}}{\ln 2} - \frac{-MQ.P_i}{\ln 2} \quad (23)$$

We receive:

$$P_t = \frac{MQ.P_i(1 - 2^{-\frac{Y}{MQ}})}{\ln 2} \quad (24)$$

Thus we obtained a formula that can be used to calculate the total performance of a given computer system / component for Y years. In order to find the average performance for the period we can divide the total (sum) performance by the number of years (the length of the period):

$$P_a = \frac{MQ.P_i(1 - 2^{-\frac{Y}{MQ}})}{Y \ln 2} \quad (25)$$

where P_a is the average performance in Y years.

We will demonstrate the possible application of the proposed formulas by a specific example. Let's suppose a company has to buy a workstation (or several). For clarity we will simplify the example by reducing the possible choice to only CPUs and more specifically their frequency, which we will equal, to speed. In a real-world situation the measure of speed would be the result of the most appropriate for the task benchmark test. When purchasing, the company has evaluated that its minimum requirements are for a 1 GHz CPU, so that is the minimum absolute performance necessary. Naturally the company would buy a faster processor. Let's consider 2 hypothetical options for a 2.4 GHz workstation and a 3 GHz workstation. We will use the formulas (11) and (25) and find the number of years that the company can use each of the workstations and what would their average performance be.

For the 2.4 GHz workstation we find:

$$Y = MQ \log_2 \frac{P_i}{P_b} = 2 \log_2 \frac{2.4}{1} \approx 2.5$$

In other words, this workstation can be used 2 and a half years. The average performance it will provide is:

$$P_a = \frac{MQ.P_i(1 - 2^{-\frac{Y}{MQ}})}{Y \ln 2} = \frac{2x2.4(1 - 2^{-\frac{2.5}{2}})}{2.5 \ln 2} \approx 1.6$$

That means that the workstation would have an average (relative) performance of 1.6 GHz for the period. Similarly we can calculate the values for the 3 GHz workstation:

$$Y = MQ \log_2 \frac{P_i}{P_b} = 2 \log_2 \frac{3}{1} \approx 3.2$$

This workstation could be used 3.2 years.

$$P_a = \frac{MQ.P_i(1-2^{-\frac{Y}{MQ}})}{Y \ln 2} = \frac{2x3(1-2^{-\frac{3.2}{2}})}{3.2 \ln 2} \approx 1.8$$

For the period its average performance would be 1.8 GHz. In a real-world example the company can also perform a cost and efficiency analysis by considering the price of the workstations and the value they bring (be it life or average performance).

Conclusion

The increased competition and the globalizing world are challenging both business companies and households to find new way of optimizing their costs. As ICT spending represent a significant share of business and personal budgets improving its efficiency is of great importance. Concentrating on computer hardware, our study demonstrated that performance could be used as a measure for value but also that it must be analysed in perspective considering the exponential increase of needs in time. The proposed methodology and mathematical apparatus can help business and ordinary users optimize their choice when purchasing computer hardware. A further development of the study and its application would be to consider price and costs and analyse not only performance by itself but also its economic efficiency.

References

Gartner. (2013). Total Cost Of Ownership (TCO) Definition. Retrieved from http://www.gartner.com/it-glossary/total-cost-of-ownership-tco/

International Monetary Fund. (2012). World Economic Outlook database. Retrieved from http://www.imf.org/external/pubs/ft/weo/2012/01/weodata/download.aspx

International Telecommunication Union. (2010). The World in 2009: ICT Facts and Figures. Retrieved from http://www.itu.int/ITU-D/ict/material/Telecom09_flyer.pdf

Internet World Stats. (2013). World Internet Usage Statistics News and World Population. Retrieved from http://www.internetworldstats.com/stats.htm

Kanellos, M. (2005). New Life for Moore’s Law. Retrieved from http://news.cnet.com/New-life-for-Moores-Law/2009-1006_3-5672485.html

Maraia, V. (2005). The Build Master: Microsoft's Software Configuration Management Best Practices. Boston: Addison-Wesley Professional.

Moore, G. (1965). Cramming More Components onto Integrated Circuits. Electronics, 114–117.

Semiconductor Industry Association (SIA). (2013). Global Sales Report. Retrieved from http://www.sia-online.org/industry-statistics/global-sales-report/

Spiegel, M. (1998). Schaum's Mathematical Handbook of Formulas and Tables. New York: McGraw-Hill.

Sulov, V. (2012). The Development of Hardware Performance. National Economic Archive, Year LXV, Book 3, 39-57.

Wikipedia. (2013a). Transistor count. Retrieved from http://en.wikipedia.org/wiki/Transistor_count

Wikipedia. (2013b). Windows NT. Retrieved from http://en.wikipedia.org/wiki/Windows_NT

World Information Technology and Services Alliance. (2004). Digital Planet. Arlington.

World Information Technology and Services Alliance. (2010). Digital Planet. Arlington.