Journal homepage: https://devma.com.ua/en

DEVELOPMENT MANAGEMENT

UDC 303.732.4: [004.9:005.336.4]
Doi: 10.57111/devt/4.2024.64

Vol. 23, No. 4. 2024

Intellectual capital of IT companies in the development processes of innovative technologies and digital transformations: Historical and genetic analysis

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Abstract. In the context of digital transformation development, the role of IT companies, which contribute to the creation, implementation and development of innovative technologies, is growing. However, taking into account that innovation formation in the economy is a long-term process, it provides for a systematic study, particularly from a historical point of view, therefore the purpose of this article was to conduct a historical-genetic analysis of the IT sphere and the role of its intellectual capital in the processes of emergence and development of innovative technologies. A systematic and comparative analysis was used in the article to conduct a historical-genetic study of the intellectual capital of IT companies within the framework of the theory of technological structures and the innovation theory of the Austrian-American economist and historian of economic thought Joseph Schumpeter. The analysis was carried out to trace the emergence of the IT sphere. In the course of the study, the main achievements of the IT sphere have been analysed, the basic innovations in the IT sphere within the framework of innovation waves, their role and importance have been described, the role and influence of intellectual capital in these processes have been analysed. Starting with the fourth innovation wave, when the first developments in intellectual capital appeared, a parallel historical-genetic analysis of the IT sphere and intellectual capital has been conducted. The correlation of innovations emergence in the IT sphere with the stages of Joseph Schumpeter's innovation waves and the reason for the reduction of their duration has been revealed. It has been discovered that the implementation of digital transformations and related innovative technologies strongly depends on the quality of the intellectual capital of the IT sphere, which concentrates intellectual efforts when creating solutions aimed at accelerating various economic and management processes. The results of the conducted research provide a more systematic idea of the origin of the intellectual capital of IT companies and its connection with the development of innovative technologies and digital transformations, which has both theoretical and practical significance

Keywords: evolutionary-historical analysis; digitalisation; intangible assets; IT industry; Schumpeter's innovation theory

Article's History: Received: 10.05.2024; Revised: 01.10.2024; Accepted: 17.12.2024

INTRODUCTION

The issue of digital transformations and innovative technologies in the economy is receiving a lot of attention from both the authorities and the business, as digital technologies can stimulate economic growth, accelerate a number of business processes and increase their efficiency, as a result contributing to increasing the competitiveness of economies and businesses, as well as their development. It is also worth mentioning that digital transformations

Suggested Citation:
Starkova, O., & Andreichikov, O. (2024). Intellectual capital of IT companies in the development processes of innovative technologies and digital transformations: Historical and genetic analysis. *Development Management*, 23(4), 64-75. doi: 10.57111/devt/4.2024.64.

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give access to large volumes of data that can be used to make more informed decisions. The use of digital technologies also contributes to increasing transparency, speed and efficiency of management processes. The introduction of digital technologies ensures new high-quality levels of interaction with customers, providing a more customised approach. Overall, digital transformations are a necessary prerequisite for a sustainable development and growth of organisations in the digital economy. However, favourable conditions must be created for the implementation and maintenance of all these transformations and the development of digital economy.

It concerns the IT sphere, which directly depends on the possibility of these transformations and their quality, which was studied by O. Andreichikov (2024). Infrastructure, science and education, which are engaged in fundamental research and provide training for IT specialists, require support and significant investments. As discovered by O. Starkova & O. Andreichikov (2024), IT companies largely depend on their intellectual capital (IC), the core of which is human capital, characterising IT services as intellectual, as the main part of their added value is produced by highly qualified labour. Requirements for candidates at the junior level position in IT companies around the world support this idea. Although, there used to be a single basic requirement for the first programmers – to pass a logic test – which is the first requirement for human capital in the IT field.

IC as a factor of development and innovation in 2024 is considered by scientists in various aspects and scopes. In particular, there are scientific works, which have established the connection of the intelligence quotient (IQ) of nations with economic growth, their cause-and-effect nature and the direct impact of the IQ of nations on the gross domestic product (GDP) of countries, which was particularly investigated by G. Francis & E.O.W. Kirkegaard (2022). It is worth paying attention to T. Shestakovska & T. Yarovoi (2020) work, in which a systematic analysis of IC management experience at the country level was carried out. At the current stage of the development of ideas about IC, the study of IC in terms of creating innovations given the digitalisation of the world's economies are of particular scientific and practical interest. Similar studies were partly carried out by T. Korytko & I. Bryl (2021), who substantially analysed the relationship of IC with the effectiveness of creating company value at the expense of human capital on the example of the Private Joint-Stock Company "Novokramatorsk Machine-Building Plant" and conducted a systematic analysis of IC measurement methods during digitisation. In addition to this work, the authors can mention a study of the nature of intellectual entrepreneurship in the conditions of digital economy, which is thoroughly covered by H. Ostrovska *et al.* (2021) and S. Revellino & J. Mouritsen (2023) in their papers. A few works concentrate on a specific study of IC of IT companies that have become centres of creation of innovative digital technologies and their suppliers. In particular, researchers S. Madhavaram *et al.* (2023) analysed data from 200 IT companies and concluded that IC contributes to competitiveness by creating opportunities for software development and innovation. Scholars P. Shaneeb & M. Sumathy (2021), investigating the impact of IC on the performance of 88 Indian IT companies, discovered that investment in staff training and development leads to increased profitability, while management structure and policies have a significant impact on return on assets of IT companies.

However, in order to fully ensure the effective management of IT companies on the basis of sustainable development, it was necessary to conduct more in-depth and fundamental systematic research, which aimed to conduct substantial, functional and historical analysis. This is the only way to get a complete and correct idea about the system, especially such a complex and poorly formalised one as IC of IT companies. The lack of scientific papers on a systematic historical and genetic analysis of IC of IT companies in the context of IT sphere defined the purpose of writing this article. During the historical and genetic research, the following methods were applied: a chronological method for determining the sequence of main innovations emergence in the IT sphere and their correlation with Schumpeter's innovation cycles; a comparative-historical analysis for identifying the impact of the IT sphere on innovation waves; a heuristic method for discovering new facts and establishing new relationships between IC of IT companies and the emergence of innovative technologies and digital transformations. Moreover, the methods of system analysis, synthesis, scientific abstraction and generalisation were also used to combine information from various sources to create a holistic view of historical events and processes in the context of IT industry development. It is also worth mentioning that, given the fact that the first significant findings and the emergence of the IT sphere itself took place at the beginning of the 20th century, historically, genetic research began from the third innovation wave.

JOSEPH SCHUMPETER'S INNOVATION WAVES

Historicism, as a dialectical principle of studying and evaluating objects and phenomena in their historical development, based on principles of a systemic approach, consists in the study of the past system, the identification of principles of its development, as well as regularities of its future behaviour, that is, in forecasting various aspects of its further functioning, which is part of a systematic historical research directed outwards. Only such systematic research can ensure the acquisition of knowledge necessary for making right decisions on the improvement of the system and the development of effective methods of its management, especially in the context of sustainable development and taking into account historical features of its formation.

In the context of the historical and genetic analysis of IC of IT companies' in the process of developing innovative technologies and innovations as such, it is appropriate to take the theory of technological structures and the innovation theory of the Austrian-American economist and historian of economic thought J. Schumpeter as a basis, who introduced such concepts as "innovation" and "creative destruction" based on M. Kondratiev's works on the theory of long waves (hereinafter K-waves) with a period of 50 ± 10 years (from 40 to 60 years), and also proved that the causes of cyclicality in the economy are the processes of innovation formation (Narkus, 2012). Cyclicality in the economy was considered by many scientists, who distinguished waves with different periods. In particular, the cycles with a period of 15 to 20 years were discovered by the Laureate of the Nobel Prize in Economics S. Kuznets in 1971, medium-term cycles with a period of 7 to 11 years were discovered by the president of the French Society of Social Economy C. Juglar, which were later developed in the investment theories of crises by the Ukrainian economist M. Tugan-Baranovsky, and short-term cycles with a period of 3-4 years were substantiated by the British statistician J. Kitchin. The latter cycles are particularly interesting given that in the modern economic theory their mechanism is associated with a delay in the information flow (temporary lags), which affects management decision-making, therefore, as J. Kimani & M. Kibera (2023) pointed out, they are also referred to as The Kitchin Inventory Cycle. Moreover, as E.A. De Groot *et al*. (2021) argued in their paper, Schumpeter suggested that the given cycles with different periods are related and one large K-wave consists of six Juglar cycles, and one Juglar cycle encompasses three Kitchin cycles.

A characteristic feature of each new K-wave is the mass introduction of epoch-making scientific discoveries and inventions. As soon as there is a chance to make the production of brand-new products much cheaper, making them available to the majority of buyers, these new goods cause a stir, stimulating mass production and employment. As a result, the cost and prices of this product decrease, which increases consumer demand and the feedback mechanism accelerates the increasing K-wave, leading to a boom. In other words, innovations and large investments in these innovations must converge at one point. D. North, the winner of the 1993 Nobel Prize in Economics and one of the founders of cliometrics (the direction of new economic history) supports this idea, emphasising that new intellectual production is directly related to innovative activity, which, together with investments, is the basis of economic prosperity (Telles, 2024).

As I. Yehorov *et al*. (2020) pointed out, according to J. Schumpeter's innovation theory, each cycle of development (long wave) consists of two parts: innovative – the creation and introduction of new technologies, and imitative – their spread. The innovative part (basic innovations) is a shorter phase of the creation and introduction of innovative technologies (the increasing stage of the K-wave), and the imitative part (improving innovations) is a longer phase of the spread of new technologies (the decreasing stage of the K-wave). As L. Kovchuga (2021) highlighted, the German economist G. Mensch added the third part to them – short-term, caused by so-called pseudo-innovations: minor improvements in goods, technologies, management methods, etc. J. Schumpeter's innovation cycles do not have a clear time frame and depend on the perfection of the new technology, affecting the time spent in the complete cycle. Due to this, there is no clear established view on their duration, as well as their chronological correlation with technological structures among modern scientists. However, L. Hu *et al*. (2023) provided examples of a systematic approach to their systematisation and overview in their work. According to The World Economic Forum, innovation waves have the following time limits (Waves of change..., 2021) (Table 1).

Table 1. Periodisation of waves

Wave number	Years	Duration
First wave	1785-1845	60 years
Second wave	1845-1900	55 years
Third wave	1900-1950	50 years
Fourth wave	1950-1990	40 years
Fifth wave	1990-2020	30 years
Sixth wave	2020-2045	25 years

Source: developed by the authors based on Waves of change: Understanding the driving force of innovation cycles (2021)

Thus, the duration of innovation waves shortens with each subsequent cycle: in the first wave, the economy reached its "peak" and "bottom" in 60 years, and in the fifth wave, where software, the Internet and mobile communication became the most important innovations, these stages took about 30 years, and subsequent waves may be even shorter. Such modern researchers as A. Espinosa-Gracia & J. Sánchez-Chóliz (2023) have the similar opinion regarding the shortening of the wave duration, who concluded that the cycles are shortened due to the emergence and achievements in the field of information technology and computers. That is, the development of IT technologies acts as a catalyst and driver for new discoveries and solutions that change traditional business methods and management approaches. Summing up, it should be mentioned that the analysis of waves of all types is necessary for forecasting the prospects of long-term and medium-term technical and technological development and innovative transformations in order to choose appropriate strategies for the development of national economies, economic sectors and individual economic entities. In the course of the study, historical periods of J. Schumpeter's innovation waves and related innovative transformations were considered in the context of the emergence and development of the IT industry, as well as its contribution to scientific and technical progress, which creates new opportunities for economic growth and increased competitiveness.

JOSEPH SCHUMPETER'S THIRD INNOVATION WAVE (1900-1950)

Before considering J. Schumpeter's third innovation wave, it should be mentioned that historians consider the appearance of the first machine in 1725, which was controlled by a perforated paper tape and was invented by a Lyon inventor B. Bouchon, as an early prototype of software. Later in 1804 (during the first wave of innovation, 1785-1845), another French inventor, loom adjuster J.M. Jacquard improved B. Bouchon's work and for the first time used punched cards instead of ribbons to create a patterned fabric and invented a way to automatically control the thread during the operation of the loom, which was later named the Jacquard loom in his honour. J.M. Jacquard's important achievement was that his machine used a universal binary code according to the principle "there is a hole" – "there is no hole". This machine was ahead of its time and became a prototype of the first computer devices. The idea of using punched cards was adopted by C. Babbage in 1830 for his analytical machine, which final development was completed by his son H.P. Babbage, who in 1906 together with Munro's workshop built a working model of C. Babbage's analytical machine (Schaffer, 2019). The programming profession itself appeared two years before the end of Schumpeter's first wave in 1843, when the British mathematician A. Lovelace described an algorithm for calculating Bernoulli numbers for an early version of C. Babbage's analytical machine, which was never built during her life. However, A. Lovelace was later recognised as the world's first programmer and her description was recognised as the first program designed for a computer. Also, it was A. Lovelace who first used the terms "cycle", "working cell", "memory cell" and others (Story of the Jacquard invention, n.d.).

Consideration of J. Schumpeter's third innovation wave can be started with an event that took place 10 years before its beginning in 1890 and determined the basic innovation for the entire wave, namely with the first machine census of the US population, during which a static tabulator of the founder of modern automatic calculations H. Hollerith was used to calculate data. As G. Strawn (2023) pointed out, H. Hollerith's invention was supplemented by a high-ranking official from the Census Bureau, J. Billings, who suggested producing tabulation using punched cards. It inspired H. Hollerith to start his own business, The Hollerith Electric Tabulating System, and after a successful census in 1896, he founded the Tabulation Machine Company, which became one of four businesses that merged into Computing Tabulation Recording Corporation (CTR) in 1911. The new company called CTR existed during 13 years and afterwards in 1924 was renamed International Business Machines (IBM) – one of the techno-giants, which during the Second World War contributed to designing several high-speed electromechanical calculators that were the forerunners of electronic computers. Moreover, throughout the 20th century IBM employees developed a number of innovative technologies, being their pioneers and some of them even became Nobel laureates (Edgar F. Codd. The inventor..., n.d.; IBMers, n.d.).

In 1918, the German electrical engineer, Doctor of Technical Sciences A. Scherbius patented the most complex encryption machine in the history of mankind Enigma with 159 quintillion different combinations of symbols and numbers, making a significant contribution to the development of cryptography for military and civilian intelligence (100 years..., 2024). According to Schumpeter's theory of innovation, the beginning of the 1920s marks the peak of the third wave. With the help of tabulators, a prototype of a local computer network was created in the Kaufmann's department store in Pittsburgh during 1932-1933. A system consisting of 250 terminals connected by telephone lines with 20 tabulators was created there. Terminals were used to read data punched in the form of holes on product labels then these data were processed by tabulators (accounting machines) and an invoice was issued for the purchase (Heide, 2009). In 1936, the outstanding English mathematician and cryptographer A. Turing proposed an abstract computing device "Turing Machine", which can be considered as a model of a general-purpose computer, which made it possible to formalise the concept of an algorithm and is still used in many theoretical and practical studies (Da Silva *et al.*, 2024). With his scientific works, A. Turing made a generally recognised contribution to the foundations of computer science, as well as to the theory of artificial intelligence (AI) and cybernetics.

In 1938, the German engineer and one of the pioneers of computer engineering, K. Zuse, created the first limited-programmable binary computing machine Z1 at home with data input, using the keyboard in the decimal numbering system in the form of floating-point numbers (Konrad Ernst Otto Zuse, n.d.). In 1939, with the support of the German Research Institute of Aerodynamics, the improved Z2 was released, which was already put into operation, and in 1941 Z3 was released – the first fully functional program-controlled and freely programmable computing machine, which was able to calculate in binary floating-point code and all features of a modern computer. A little later, K. Zuse also created Plankalkül – the world's first high-level procedural programming language.

In 1943, the Colossus computer was created at the Bletchley Park estate (Milton Keynes, England) to decipher cipher texts of the German Enigma mechanical encryption machine. During 1943-1945, the US Army Ballistic Research Laboratory commissioned scientists from the University of Pennsylvania E.J. Presper and J.W. Mauchly to create the first universal 30-ton Electronic Numerical Integrator and Computer, which became the prototype of most modern Turing-complete computers (ENIAC..., n.d.). In 1944, the US Navy commissioned IBM to create a 5-ton relay-mechanical machine "Mark I" or Automatic Sequence Controlled Calculator (ASCC) – an automatic computer controlled by a program. In 1948, the Manchester Small-Scale Experimental Machine (SSEM) was also launched – the world's first stored-program computer built on the basis of Von Neumann architecture, created by scientists from the University of Manchester F.C. Williams, T. Kilburn and G. Tootill on commission of the British Ministry of Supply, responsible for military research (including guided nuclear weapons) (Tindsley, 2023). In 1950, at the end of Schumpeter's third innovation wave, the National Physical Laboratory (Great Britain) completed the development of the Pilot Automatic Computing Engine (ACE) – a small-scale programmable computer with a stored program based on the Turing machine model.

Summarising the overview of Schumpeter's third innovation wave in the context of innovations that took place in the IT field, it can be said that this period of fundamental research was possible due to the intelligence of such scientists as A.M. Turing, J. Presper, J. Mauchly and others (ENIAC..., n.d.). The main results of the wave include the formalisation of the concept of algorithm – one of the key concepts in informatics and computer sciences, the development of the first high-level procedural programming language, the emergence of working samples of computer technology (basic innovations), which are improved several times (simulation innovations). All these achievements significantly accelerate the development of science and technology. The research results obtained during this wave, which were financed from public funds through various ministries, were not yet widely commercialised and were mainly used in the public sector in such areas as encryption and cryptography (military and defence industry), various computing (space, nuclear industries etc).

JOSEPH SCHUMPETER'S FOURTH INNOVATION WAVE (1950-1990)

Semiconductors, the growth of the number of electronic computers, industrial robots and personal computers, as well as the emergence and development of the global Internet, the prototype of which was the computer network Advanced Research Projects Agency Network (ARPANET), created in 1969 in the USA by the US Defence Advanced Research Projects Agency (DARPA) – are the defining innovations during this wave. It should be mentioned that the beginning of this wave almost exactly coincides with the beginning of the third industrial revolution (beginning of 1960) or the third post-industrial wave of A. Toffler. As I. Petrunenko *et al*. (2022) pointed out, according to E. Toffler's estimates, the third wave should completely replace the second at the end of 2025. Moreover, during Toffler's third wave in the conditions of a post-industrial society, knowledge and information became the main drivers of economic development and transformed into a new type of intangible assets – information capital. As a basic innovation within the framework of Schumpeter's fourth innovation wave, software can be singled out, the market of which as an independent industry began to shape just at the beginning of this wave and determined the main vector of development for this period.

The term "software" in 1958, as well as the term "bit" (binary digit) in 1946, was first used by a mathematician from Princeton University, a member of the US National Academy of Sciences J. Tukey (John Tukey, unsung man..., 2024). In the same 1958, the term "information technology" appeared, which was applied by H.J. Leavitt & T.L. Whisler (1958) in the Harvard Business Review magazine, and IBM natives E. Kubie and J. Sheldon registered the first private IT company in this market in 1955. Computer Usage Company, which independently developed software for modelling oil flow for the California Research Corporation, became a pioneer in the field of programming services. Until then, software was developed either by computer users or by a few commercial computer vendors, such as IBM, which in the 1950s also developed the high-level programming language FORTRAN (n.d.) (FORmula TRANslator) that was widely used primarily for scientific and engineering calculations, contributing to the creation of a large number of programs and subroutine libraries written in it.

In 1952, the British computer scientist A. Glennie, working together with A. Turing, created Autocode, which is considered the world's first compiler. The same year, mathematician G. Hopper developed the theory of machine-independent programming languages and the A 0 System compiler, which translated mathematical code into binary machine code. Moreover, in the same year FLOW MATIC was developed under her leadership – the first data processing language, using English words instead of numbers (Barfield, 2021). In 1953, the world's first computer science training program appeared in the computer laboratory of the University of Cambridge (Goddard, 2019) and later in 1962, the first computer science faculty appeared in the USA at Purdue University (Department of computer science..., 2023).

In 1956, IBM introduced the first hard disk, the IBM 305 RAMAC (n.d.) (Random Access Method of Accounting and Control), which weighed almost a ton and had 5 MB of memory. A little later, in 1961, D. Gregg invented the optical disc and in 1963, D. Engelbart invented the computer mouse (History of IT, 2024). The world's first fully automated electronic machine for processing checks and keeping current accounts, the Electronic Recording Machine Accounting (ERMA) began its operation in one of the departments of Bank of America in 1959 (Spicer, 2023). In 1968, IBM in collaboration with Rockwell and Caterpillar created the Information Management System (IMS) for the Apollo space program – a hierarchical database (BD) and information management system that enabled transaction processing (Introduction to IMS, n.d.). This IBM development was a significant improvement after the Integrated Data Store database management system (DBMS), based on the data navigation model, which was developed in 1963 by the American computer scientist and Turing Prize winner Charles William Bachman, who later also developed a new version of DBMS with a network model called Integrated Database Management System (IDMS), which supported IBM mainframes.

Despite the fact that in the 1970s, a period of stagflation began in the USA, which was primarily caused by a sharp increase in oil prices, leading to a slowdown in the pace of technological development and innovation, the IT sector continued to develop actively. In 1970, IBM employee E. Codd first described the principles of creating relational databases in the work "Relational Model of Data for Large Shared Data Banks" (Edgar F. Codd. The inventor..., n.d.). The first database was developed by a group of students and scientists at The University of California in Berkeley, who created the INGRES relational database, which used the QUEL query language. In 1973, IBM started to develop its own relational database System R, which used the Structured Query Language (SQL) for the first time, developed by IBM scientists D. Chamberlin and R. Boyce and which still remains the main language for working with databases (Mucci, 2024).

In 1971, R. Tomlinson developed a program for exchanging messages between computers, Send Message (SNDMSG), which is considered the prototype of e-mail, D. Noble invented the floppy disk, the Intel company created the first commercially available microprocessor Intel 4004 (The history of IT, 2024). In addition, in the same year, the first computer virus called "Creeper" was created by B. Thomas. The IT sphere received a more significant shift in 1981 after the agreement between IBM and Microsoft, when the era of operating systems for personal computers and the first software for them began (Miller, 2021). In the conditions of capitalist relations and increasing globalisation, as well as due to the development of the Internet, it contributed to the formation of the market of personal gadgets and significantly revived the development of software, attracting the attention of businesses and investors. In this way the IT sphere gradually went beyond state funding and began a new stage of development. In the same 1981, a new economic course called Reaganomics began in the USA, the main features of which were the stimulation of demand, investment and innovation, being the main prerequisite for the appearance of the K-wave, which in this case contributed to the development of Schumpeter's fifth innovation wave.

Then in 1985, the NASDAQ-100 index of technology companies (NASD Automated Quotations) appears on the NASDAQ exchange, which was created back in 1971 and was the first in the world to provide automated stock quotations, allowing investors to trade quickly and transparently electronic securities of 100 technology companies such as Apple, Microsoft, Intel, Oracle, Cisco Systems and others, and in 1998 NASDAQ was the first in the world to provide online trading (NASDAQ, n.d.). The emergence of the C++ and Objective-C programming languages, the creation of the Berkeley Internet Name Domain (BIND) – the first Domain Name System server (DNS server) at the University of California at Berkeley, where a Unix-like operating system Berkeley Software Distribution (BSD) was developed, which was used by various commercial startups in the 1980s, were significant events of the 1980s in the IT field (The history of BIND, n.d.). In 1985, the first domain names darpa.mil, darpa.edu, darpa.net, darpa.gov, darpa.arpa, symbolics.com were registered (Baltes, 2024) and in 1989 the first private commercial Internet provider The World appeared, which provided access to the global Internet (Who invented the Internet, 2023). During the 1980s, decision support systems, expert systems and databases were also actively developing, the widespread use of AI on personal computers began due to the development of the method of backward propagation of errors, the direction of computer games was developing, MS Word (1983) and Windows 1.0 (1985) appeared, the first notebook from Apple (1989), and such companies as Microsoft, MicroPro and Lotus Development already had annual software sales of tens of millions of US dollars in the 1980s.

Summarising the overview of Schumpeter's fourth innovation wave, it can be said that even in unfavourable conditions and crisis phenomena in the economy, the IT sphere has proven itself as a powerful factor of innovative development and a driver of the development of economy as a whole. The most important challenge of this period was information and its rapid accumulation, which required software for its storage and processing, in particular various databases, the existence of which, in turn, would be impossible without the appropriate hardware, in particular hard and laser disks. During this innovation wave, the term "intellectual capital" was used for the first time. E.A. Aduna-Lira (2022) pointed out that it was used in 1969 by the famous American Keynesian economist and the author of the theory of technical determinism and convergence J. Galbraith in his letter to the Polish economist M. Kaleckiego, to emphasise workers' intellectual activity among. It is worth mentioning that a little earlier in 1962, the Austrian-American economist F. Machlup introduced the concept of "knowledge industry", meaning five sectors of economy: education, scientific research and development, means of communication, information machines and information services. It was stipulated by the fact that the sphere of services, science and education during the fourth innovation wave gradually began to prevail over industry and agriculture, where scientific knowledge also began to be actively used, contributing to the formation process of a post-industrial society. The term "post-industrial society" itself appeared in 1958 in the works of professor of social sciences at the University of Chicago D. Riesman, and already in 1973 the concept of post-industrial society was most fully and comprehensively substantiated by the outstanding American professor of sociology at Harvard University D. Bell, who thoroughly analysed main trends in changing relations of social production sectors, the formation of service economy, the formation of scientific knowledge as an independent element of production forces, and the concentration of society around the axis of knowledge production.

In particular, after the appearance of the world's first computer science program, the training of specialists in this area began. Since 1966, the number of Computer Science graduates with bachelor's degree in the United States was steadily increasing until 1986, when it reached 40,000 graduates per year (National Science Board, 2000). For comparison: in Ukraine, 47,100 applications were submitted for the computer science degree during the admission campaign in 2021 (Admission campaign…, 2021). Thus, due to the growth of education prestige, the knowledge industry gradually gained a new sense, leading to the emergence of a whole layer of qualified specialists, including programmers, managers, intellectual workers, which contributed to the increase of intellectual potential in the process of "processing" the biosphere into the noosphere, the main generator of which, according to V.I. Vernadsky's doctrine about the noosphere, is human thought, which is a part of human capital. Moreover, the overview of the fourth wave suggested that the number of different IT solutions increased significantly during this period, which correlates with the increase in the number of trained specialists in the field of computer science. This once again proves that human capital is the core of the IT sphere.

Therefore, when conducting a parallel analysis, it becomes evident that the initial phase of the IT sphere development (1950 – the appearance of FORTRAN, 1953 – the first educational program in computer sciences, 1955 – the first private IT company, etc.) and the emergence of the terms "post-industrial society" (1958), "knowledge industry" (1962) and "intellectual capital" (1969) have a logical sequence and a chronological connection. This period (1950-1970) was the rising stage of the K-wave, during which the role of intellectual activity, information technology and computerisation significantly increased in science, scientific and technical progress and economy (trade, banking, railway transport, etc.). This trend attracted attention of such economists as J. Galbraith and F. Machlup, who initiated the research of IC and intangible assets.

JOSEPH SCHUMPETER'S FIFTH INNOVATION WAVE (1990-2020)

The Internet was the basic innovation for this wave: web1 (1991-2005) is a read-only network, web2 (2006-2020) is a social participation network and the internet economy, related to it. At the very beginning of the wave in 1991 the development of the Internet was facilitated by the HyperText Markup Language (HTML) technology and the first WorldWideWeb browser (later renamed Nexus), developed by the British physicist T. Berners Lee from the Swiss research institute Conseil Européen pour la Recherche Nucléaire (CERN), who in 1994 founded the World Wide Web Consortium (W3C) – the main international organisation that still develops and implements technological standards for the Internet (A short history…, n.d.). Also in the 1990s, a number of programming languages such as Python, PHP, Java, JavaScript, AppleScript, Visual Basic, etc. emerged and in 1997, Wireless Fidelity (Wi-Fi) appeared.

According to the World Bank Group, 40 million people had access to the Internet in 1995, this number increased to 400 million in 2000 and it exceeded one billion people in 2005 (Individuals using the Internet..., n.d.). Such spread of the Internet and PCs attracted the attention of business, whose owners began to massively create websites for their companies and transfer their business processes to the Internet in order to promote their services, with subsequent entry into the NASDAQ stock exchange, where just mentioning the word "internet" in the company's profile would increase its value by dozens of percent. However, such business models were ineffective as the funds that should have been spent on supporting operational business processes were spent mainly on marketing campaigns and advertising on television and in the press. According to the data of the World Bank Group, the number of registered shares on American platforms increased to a record 8.09 thousand in 1996 (to compare: in 2019, there were 3.9 thousand, i.e. half as much) (Listed domestic companies..., n.d.). In addition, in the 1990s, 2,300 alliances or 44% of all alliances created during that time in the world, were technological and related to such information technologies as computer software and hardware, telecommunications, industrial automation, and microelectronics (National Science Board, 2000).

This trend led to the "dotcom crisis" in 2000, studied by S. Barber (2022). According to Schumpeter's theory, the recession started after the peak of the fifth wave and the NASDAQ index began to drop on the market, losing about 80% of its capitalisation due to the bankruptcies of more than 800 companies, resulting from the information economy of Silicon Valley. The main causes of this crisis were stipulated by excessive investment and speculation around the internet economy rather than rapidly developing innovative IT technologies. Investors invested in these "tech" companies with a website, disregarding the fact that they were mostly unprofitable. M. Meeker's portfolio from the Morgan Stanley bank can serve as an example of a risky investment policy, which included about two hundred internet companies with a total market value of 450 billion US dollars, whereas, their total profitability was negative and amounted to minus 6 billion US dollars at the end of 1999, just before the crisis began (New horizons..., n.d.). Individuals, lacking knowledge and being influenced by the aggressive advertising, actively invested about 150 billion US dollars in this field in 1998, 180 billion in 1999, and 260 billion in 2000, when the collapse had already begun. Finally, according to analysts' estimates, 100 million private investors lost 5 trillion US dollars in stocks by 2002 (Venture capital..., 2024). To overcome the recession in the 2000s, it took companies such as NASDAQ, Microsoft, Amazon and other technology leaders about 15-17 years (that is, until 2015-2017) to restore results achieved in 2000 before the collapse during the "dotcom crisis". However, it should mention that the innovative component of this Schumpeter's wave gave rise to the imitative component, i.e. the basic innovation contributed to the emergence and improvement of innovations in dozens of industries related to the internet industry: software, network equipment, internet search services (1994 Yahoo! search and 1998 Google), online advertising, AI, semiconductors, cloud services, delivery services and many others, still working for the internet industry.

The beginning of the 2000s was also a period of the social network boom as a new version of the Internet web2. The term "social networks" was suggested by the English sociologist J. Barnes in 1954 and was widely used later in various fields of science (Bessarab *et al.*, 2021). The first prototype of a social network was the electronic bulletin board Computerised Bulletin Board System (CBBS) – a computer program for file transfer and communication via the early Internet, which was created in four weeks by members of the Chicago Area Computer Hobbyists' Exchange (CACHE) W. Christensen and R. Suess in 1978 (Metz, 2019). In 1983, there were already about 800 such boards around the world. However, social networks began to gain popularity on the Internet in 1995, when a successful American portal "classmates.com" emerged, aimed at finding former classmates, army comrades and colleagues. The site quickly gained popularity and dozens of its analogues appeared soon. However, 2003-2004 are considered the official beginning of the social network boom with LinkedIn, MySpace and Facebook being launched in the USA and the emergence of video hosting YouTube in 2005. In 2008, the Bitcoin cryptocurrency protocol appeared, which was created by an unknown author or a group of authors under the name S. Nakamoto (What is bitcoin, n.d.). It gave a start to the entire industry of cryptocurrencies, which changed the paradigm of the economy as a whole and contributed to the development of a new version of the Internet, web3.

Summarising the results of the fifth innovation wave, it can be said that it was quite a dynamic and productive wave, during which a fundamental basic innovation was created – the Internet with a number of related directions (imitation innovations), which changed the IT sphere itself and determined its priorities, as well as influenced the general landscape of the world economy, even changing value orientations from physical to immaterial ones, which was studied by O. Starkova & O. Andreichikov (2024) on the example of the Apple company. Owing to the achievements of the IT sphere during the fifth innovation wave, in particular due to the main innovation of this wave – the Internet, the ways of conducting business and economic activity began to change fundamentally. The Internet has become a major driver of globalisation, allowing companies to easily enter international markets and exchange information in real time. E-commerce has revolutionised retail, enabling consumers to purchase goods and services from anywhere in the world. The implementation of information systems into business processes has led to the automation of many operations, increased management efficiency and reduced costs. New business models have also emerged, such as platform economies and financial technologies, which enabled small and medium-sized enterprises to compete with large corporations. Information technologies have also contributed to the development of analytics and big data processing, which has made it possible to make more informed decisions and forecast market trends with high accuracy.

JOSEPH SCHUMPETER'S SIXTH INNOVATION WAVE (2020-2045)

According to the World Economic Forum, such innovative technologies as AI, blockchain, Internet of Things (IoT) and big data have been playing an important role in digital transformation since the beginning of the 2020s (Waves of change…, 2021). Although, AI and blockchain with huge investments can be considered the main basic innovation for the current sixth innovation wave. In particular, 2020 was crucial for AI, when the ChatGPT was released, developed by the OpenAI company, which started raising 7 trillion US dollars for the development of this project in 2024 (Hagey & Fitch, 2024). Attention to AI is stipulated by its capacity to innovate quickly. For example, computer modelling using AI, made it possible to create new antibiotics (Duboust, 2023) and substitutes for lithium-ion batteries (Conover, 2024) in a very short time. Such achievements and digitalisation in general have become possible due to the development of the IT sphere, which in turn is very dependent on its own IC. According to Attainix Consulting, a leading company for the study and assessment of IC, at the beginning of March 2024, Microsoft's IC was valued at more than 1.38 trillion US dollars or 46% of the total capitalisation of 3 trillion US dollars, Apple's IC was valued at more than $1.31 US dollars or 48% of the total capitalisation of more than 2.7 trillion US dollars, and Nvidia's IC was valued at more than 380 billion US dollars or 19% of the total capitalisation of more than 2 trillion US dollars, which is stipulated by the fact that IC, in contrast to physical one, provides for the creation of a much greater added value (IcTracker valuation…, n.d.).

The given examples suggest that IC is an important component of modern technological companies and its application makes it possible to create innovative products with higher added value, for example, software, the development of which brings significant revenue to both private IT companies and budgets of many countries in the form of taxes and investments. In particular, in Ukraine, in 2023, the share of IT in the country's GDP was 4.9%, the contribution of the IT industry to the gross added value made up 5.5 billion US dollars, the volume of export of IT services amounted to 6.7 billion US dollars (a reduction of 8.4% compared to 2022), and the amount of involved investments accounted for 111 million US dollars (in 2022 – 631.5 million USD) (Oliinyk, 2024). Moreover, in Ukraine, 21.7% of enterprises have full-time IT specialists and another 14.6% of enterprises engage freelancers to perform information and communication technology functions (IT Ukraine Association, 2022). Such indicators are not accidental, given the modernisation and development of enterprises and entire industries in the modern world is directly connected with the development and implementation of information technologies, as they provide for production processes automatisation, productivity increase, cost reduction and overall improvement of business efficiency.

There are many examples of the implementation of modern IT solutions developed in Ukraine, which have changed the approaches and standards of doing business, as well as affected the life of every Ukrainian: the nationwide Diia system, Privat24 and Monobank banking products, services of NOVA companies (before Nova Poshta rebranding), which has gone beyond providing solely postal services and already provides digital financial services (NovaPay), produces software and web applications (Nova Digital), engages in e-commerce (Nova Global) and provides services to other well-known Ukrainian technology marketplaces such as ROZETKA, OLX, etc. This list can be enlarged with powerful world-known and popular services such as Grammarly (an AI service for checking English spelling), GitLab (a DevOps life cycle web tool), Prometheus (an online course platform) and many others.

A special attention should be paid to IT-Enterprise company, Ukrainian innovator in the field of Industry 4.0, which offers a number of high-tech solutions for industry and has many successful examples of their implementation in Ukrainian and foreign markets. In particular, such an example is the implementation of digital twins for Kharkiv manufacturer of air and space aircraft JSC FED, which implemented the Advanced Planning and Scheduling (APS) – Smart.Factory solution, designed to calculate the optimal location of production facilities to maximise production productivity (Shchehlov & Morozova, 2022). The services of IT companies are already actively used in the agricultural sector, where 10% of Ukrainian farmers already implement IT technologies in their work, using AI, IoT, drones, GPS technologies, geographic information systems, analytical systems for yield assessment and variable rationing, remote earth sensing and others (IT Ukraine Association, 2022).

Understanding the importance of human capital, IT companies actively create their own training centres and finance educational projects. In particular, during the annual conference on IT education "Synergy. IT Business & IT Education" in December 2023 with the participation of Ukrainian leading IT companies and high-ranking government officials, it was put forward that education is the first global direction that will have a long-term impact on the country's development, and innovations and development of the latest technologies is impossible without the development of science (Synergy of education…, 2023). That is, investing in the development of IC of the IT industry leads, in fact, to an increase in profit (self-growth) of capital as such, suggesting that IC has the function of capital self-growth. The above mentioned proves that IC is a very important type of capital for IT companies and its management is a priority task, since IC is now perceived as a certain internal force of modern business, which supports the necessary level of competences and gives impetus to innovation. In turn, according to CoinMarketCap, in March 2024 the crypto-economy based on blockchain technologies had a total capitalisation of about 2.4 trillion US dollars and the capitalisation of AI-related tokens had a growing trend (Top AI…, n.d.).

There are also many similar examples of developments in this direction in Ukraine (Results of digital…, 2024). In particular, the National Bank of Ukraine will have conducted an open testing of the e-hryvnia blockchain by the end of 2024, encouraging everyone to participate (Interview of Andriy Poddyerogin…, 2024). The Draft Law of Ukraine No. 10225-1 (2023) aimed at creating favourable conditions for the web3 sector in Ukraine was included in the agenda of the Verkhovna Rada of Ukraine on February 6, 2024. Kitsoft company as a part of the Public Union "Virtual Assets of Ukraine" acted as a technical partner and developed a prototype of a new generation real estate and land registry based on web3 technologies, which was presented to the Ministry of Digital Transformation of Ukraine on January 19, 2024 (Kitsoft developed…, 2024).

In addition, the Government of Ukraine has already developed and adopted a number of strategies and programs aimed at stimulating the development of digital economy. The development of electronic government is one of the key directions of digital transformation in Ukraine. It provides for transferring public services to the online mode, which makes them more available and convenient for citizens, as the example of the nationwide digital system Diia suggests. In particular, the Ministry of Digital Affairs together with the Swiss Agency for Development and Cooperation (SDC) held an event dedicated to the development of digital Ukraine in Ukraine House Davos on January 17, 2024. The domestic experience of the digital state development was presented there, in particular: the WIN-WIN innovation development strategy (Diia, Mriya..., 2024) on the creation of benefits for all involved parties. Also, electronic identification and electronic signature technology has already been widely introduced, the "paperless" operation of the state is being implemented, the penetration rates of basic electronic services and industry digital transformation are increasing. Significant work was also carried out in the direction of digital education, within which the innovative educational application "Dream" was presented on February 16, 2024 (Scaling educational opportunities..., 2024).

Taking into account the above mentioned, it can be argued that the IT sphere plays a primary role in Schumpeter's innovation waves, concentrating intellectual efforts upon creating solutions aimed at accelerating various economic processes for various industries. The study suggests that the more the IT sphere develops and the more IT solutions appear in it, the shorter Schumpeter's innovation waves become. Moreover, it is difficult to imagine the innovative economy and digital transformations without computers, the Internet, mobile banking, e-mail, various messengers, databases, etc., which resulted from the IT sphere that put an end to paper-based calculations and records. In the course of the study, it was also discovered that when imposing the stages of IT development on J. Schumpeter's innovation waves, one can see a correlation with the genesis of the innovation cycle as a process of transferring innovations into the field of application, namely: J. Schumpeter's first innovation wave – innovation or invention (application of perforated paper tapes for automating the Bouchon machine and punched cards for the Jacquard machine); the second innovation wave – innovation or a developed invention (C. Babbage's early analytical machine and A. Lovelace's first program before it); the third innovation wave – innovation (appearance of ENIAC and serial computers); the fourth innovation wave – assimilation (software development); the fifth innovation wave – diffusion or distribution (development of the Internet); the sixth innovation wave – routinisation or stable implementation of innovations (wide introduction of IT technologies, based on AI and blockchain in all spheres of life: AI-powered personal assistants, cryptocurrencies, blockchain registries, digital twins, etc.).

CONCLUSIONS

The IT sphere was shaped as an industry as a result of the emergence, further improvement and dissemination of innovations in the field of computing. Due to the emergence of the IT sphere and the solutions that were developed within it, significant progress and development was achieved in many spheres and branches of the economy (defence, space, energy, medical, banking and trade spheres, education and science, etc.). The study has discovered that the IT sphere is highly dependent on IC, the development of which is primarily related to human capital, as well as the development of education and science. As it has been discovered in the course of historical and genetic analysis, the first scientific mentions and works on IC appeared, when the IT sphere acquired systemic features with a scientific, educational and business background. A direct correlation between the number of trained personnel in the field of computer science and the number of created IT solutions was also revealed, which laid the foundation for further digital transformations and the development of innovative technologies.

The influence of the IT sphere on the economy and public administration has already reached such a level that high-ranking government officials have become engaged in the development of the IT sphere. In turn, business representatives in various industries and spheres of the economy around the world also pay significant attention and invest significant funds in the creation and development of information technologies, receiving significant improvements in business efficiency as a result. On the example of the world's largest IT companies (Microsoft, Apple, Nvidia), it was shown that IC occupies a fairly significant part – from 19 to 48% in the structure of their capital, which proves its importance in the creation of innovative technologies and digital transformations, which are created and introduced by IT companies. Thus, the importance and primary role of IC in the processes of digital transformation and related innovative technologies have been revealed in the course of the historical and genetic analysis. The obtained results are of both practical and theoretical significance for further research of IT companies' IC, its modelling, construction of application models and its management, taking into account the historical component of its development.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

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Інтелектуальний капітал IT-компаній у процесах розвитку інноваційних технологій та цифрових трансформацій: історико-генетичний аналіз

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Анотація. У контексті розвитку цифрових трансформацій роль IT компаній, завдяки яким створюються, впроваджуються та розвиваються інноваційні технології, зростає. Однак через те, що процес формування інновацій в економіці є тривалим, він потребує системного вивчення зокрема й з історичного погляду, тому метою статті було проведення історико-генетичного аналізу IT-сфери та ролі її інтелектуального капіталу в процесах появи та розвитку інноваційних технологій. Завдяки системному та порівняльному аналізу в статті проведено історико-генетичне дослідження інтелектуального капіталу IT компаній у рамках теорії технологічних укладів та інноваційної теорії австрійсько-американського економіста та історика економічної думки Йозефа Шумпетера. Аналіз проведено від початку появи IT сфери. У ході дослідження були проаналізовані основні досягнення IT сфери, описані базисні інновації в IT сфері в рамках інноваційних хвиль, їх роль та значення, а також проведено аналіз ролі та впливу інтелектуального капіталу в даних процесах. Починаючи з четвертої інноваційної хвилі, коли почали з'являтись перші наробки в напрямку дослідження інтелектуального капіталу, проведено паралельний історико-генетичний аналіз IT-сфери та інтелектуального капіталу. Виявлено кореляцію появи інновацій в IT-сфері з етапами протікання інноваційних хвиль Йозефа Шумпетера та причиною скорочення їхньої тривалості. Виявлено, що імплементація цифрових трансформацій та пов'язаних із ними інноваційних технологій сильно залежить від якості інтелектуального капіталу IT сфери, в якій концентруються інтелектуальні зусилля при створенні рішень спрямованих на прискорення різноманітних економічних та управлінських процесів. Результати проведеного дослідження дають більш системне уявлення про причини виникнення інтелектуального капіталу IT компаній і його зв'язку з розвитком інноваційних технологій та цифрових трансформацій, що має як теоретичне, так і практичне значення

Ключові слова: еволюційно-історичний аналіз; інноваційна теорія Шумпетера; нематеріальні активи; IT індустрія; діджиталізація