Technology in the Industrial Revolutions and Its Impact on the Key Performance Indicators of Organizations

Oleg Zaritskyi[a] and Oleksandr Ponomarenko[b]

[a] National Aviation University, Liubomyra Huzara Ave, 1, Kyiv, 03058, Ukraine
[b] Professional College of Engineering and Management of the National Aviation University, Metrobudivska str., 5a, 03065, Kyiv, Ukraine

Abstract

Context. The article considers topical issues of interconnection of life cycles of business, production, product models of enterprises and key indicators of their activities through the prism of the evolution of information systems, their impact on the pace of development of enterprises and the role that information systems play in industrial revolutions. Objective. The overall objective of the study is to assess the impact of information systems on the development of enterprises in the process of industrial revolutions by assessing the key performance indicators covering all perspectives (functional areas of enterprise development) of the balanced scorecard as one of the progressive systems of strategic management of organizations. Method. Formalization of key performance indicators through the mathematical apparatus was carried out using the methodology of strategic management of the enterprise - the balanced scorecard. Results. The study formalized the types of basic IS and software, their impact on the development processes of enterprises during the industrial revolutions by assessing certain key performance indicators in terms of the balanced scorecard methodology, which was first described using a mathematical apparatus. Conclusions. The main directions of transformation of modern production are defined by three global technological trends: network integration, intellectualization and flexible automation. The development and widespread implementation of IP has doubled the pace of technological revolutions and, in fact, determines all further enterprise development strategies within these technological trends. The next (fifth) industrial revolution will be defined exclusively by the development of data science and the transition to new system architectures of computing systems or their combinations, for example using neurosynaptic and quantum computers, which will allow using all the possibilities of industrial Internet of Things and Digital twin's concepts in almost real time.

Keywords

PLM, CALS, CAD, ERP, KPI, industrial revolutions, industrial Internet of things, balanced scorecard.

1. Introduction

Industrial technology has come a long way from the first attempts to mechanize production using mechanical devices and steam engines during the first industrial revolution in the XVII century to creating a single information environment using the industrial Internet of Things in the XXI century. (Fig.1).

All the efforts of the engineers of the first industrial revolution were aimed at developing machines and devices that helped workers to mechanize standard operations in order to increase productivity.

The second industrial revolution was marked by the use of electricity, the development of the assembly line and the transition to mass production. At that time the first schools of management were beginning to emerge, and F. Taylor published his seminal work "Principles of Scientific Management" (1911).

The basis of the third industrial revolution was the rapid development of IS and computers, which allowed the transition from mechanization to automation of production with the use of special software for product design and production resource management. The era of computer systems began, which quickly took a leading

Emerging Technology Trends on the Smart Industry and the Internet of Things, January 19, 2022, Kyiv, Ukraine
EMAIL: oleh.zaritskyi@npp.nau.edu.ua (O. Zaritskyi); ponomarenkos_200@ukr.net (A. Ponomarenko)
ORCID: 0000-0002-6116-4426 (O. Zaritskyi); 0000-0002-6538-0468 (A. Ponomarenko)

position in the automation of enterprise management processes. At the same time, there was an intensive development of various schools of management and corresponding concepts of management of organizations, organizational management, which studies the fundamental principles of the functioning of organizations, became popular. The first concepts of enterprise management were emerged.

The fourth industrial revolution introduced the concepts of "smart factory", "smart production", "factory of the future". Currently, these terms are used interchangeably, although "factory of the future" is a broader concept that includes "smart manufacturing" but using a single digital space and virtualization of workplaces.

The U.S. National Institute of Standards and Technology (NIST) defines Smart Manufacturing as fully integrated corporate manufacturing systems capable of responding in real time to changes in production conditions, the requirements of logistics networks and to meet consumer needs [1]. Thus, the transition to digital production at all its stages in a single information environment (the ideology of previous years CALS) with full integration with suppliers and consumers to implement rapid real-time feedback in response to any changes in the internal and external environment is assumed.

The intensive development of IS and software, which started during the third industrial revolution, has also passed its evolutionary way from two-dimensional design systems (CAD(2D)) to three-dimensional (CAD(3D)) and product data management systems (PDM, PLM) in terms of development and design management. Another development is enterprise resource management (ERM), where the starting point was the development of MRP-class systems in the late 1960s, which ended in the 2000s with the realization of full integration of organizations in a unified information environment based on ERP, CRM and SCM-class systems. Further development of IS was aimed at combining the design and development environment (PDM, PLM) with enterprise resource planning (ERP) environments using intermediate integration IS, for example in the construction field of BIM-class systems [2].

Capabilities of PLM and ERP class systems in terms of data operation, digital product models during their life cycle, access to customer supply chains in one environment, allowed to approach the implementation of the BSC concept developed in the 1990s, as one of the most effective systems of strategic management.

Thus, the basis of the industrial revolutions was the development of science and technology as a result of the discovery of fundamental physical laws in the late XVII and XVIII centuries and the development of information technology in the IX - XX centuries. The concepts of enterprise management have also undergone an evolutionary path of development, taking into account the state of technology and data availability, and since the XXI century, usually involve a combination of production and business strategies.

The object of research is the concept of industrial revolutions, which occur due to the development of various branches of natural sciences, data science and their practical implementation through information technology, transforming technological processes from a purely technical plane to an intellectual, virtual plane, combining real objects with their digital twins**.**

The subject of research is information technology and key performance indicators of the enterprise within the evolution of production models during the industrial revolutions.

The aim of research is to formalize the types of IP, their relationship and impact on the KPI of enterprises in the transition from mechanization to virtualization of production.

2. Problem Statement

Modern systems of strategic management of enterprises are presented in the studies of many schools of management and are in constant improvement and development, specifying the key aspects and metrics by which it is possible both to plan activities and to monitor the implementation of strategies. The most thorough, in the opinion of the authors of this article, is the BSC concept developed by Harvard University professors R. Kaplan and D. Norton [3].

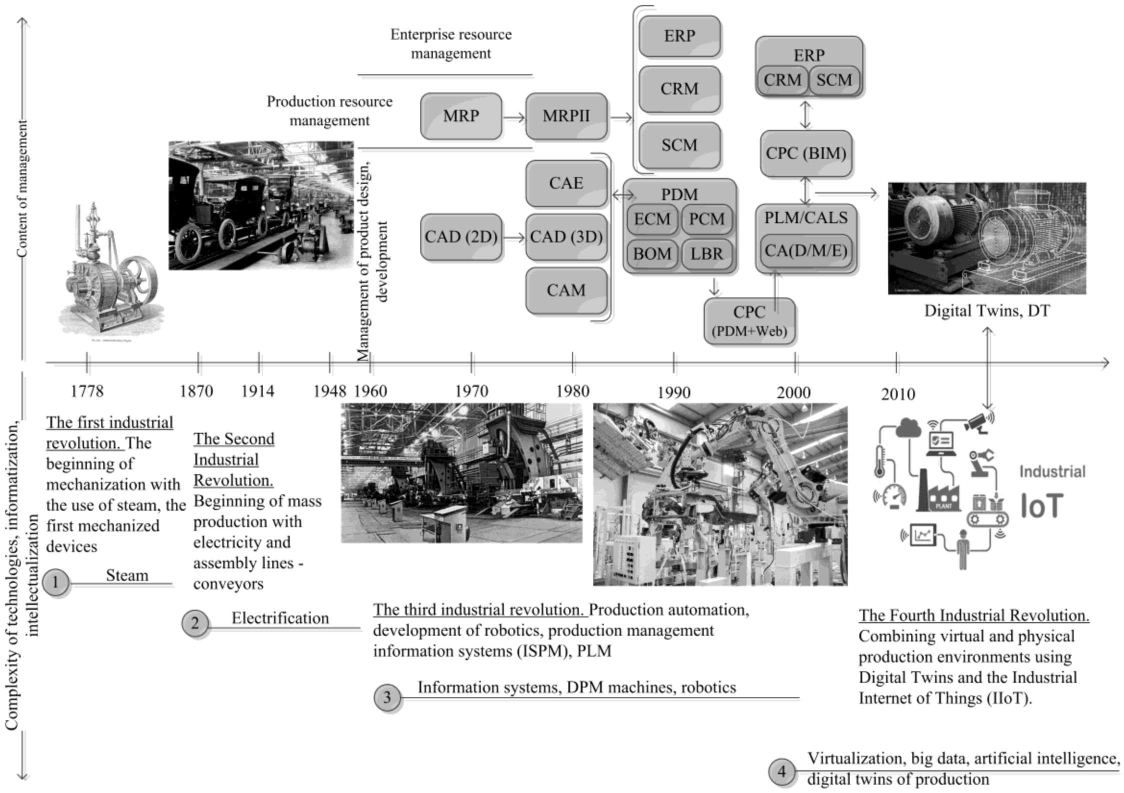

Figure 1: Evolution of technological revolutions and information system

The basis of BSC is the measurement and assessment of its effectiveness by a set of optimally selected indicators (KPI), characterizing all aspects of the company's activities, in terms of four perspectives, by their decomposition to the level of operational control (Fig.2).

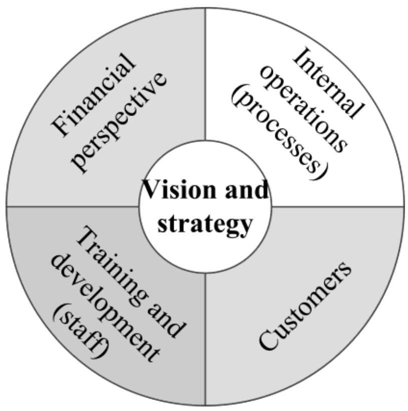

Figure 2: BSC concept

Accordingly, the model for the *i-th* scenario with *k* possible formalized strategies S_i can be written in general (1 – 4):

$$S_i = f\left(P_{N_i}\right), i = \{1...k\}, N_i \in \{F_i, O_i, D_i, C_i\} \tag{1}$$

$$f : \left(G^m_{N_i}\right) \to P_{N_i \in \{F_i, O_i, D_i, C_1\}},\ m \in \{1 \div 5\} \tag{2}$$

$$f : \left(I^m_{N_i}, R^m_{N_i}, A^m_{N_i}\right) \to G^m_{N_i}, \tag{3}$$

$$\lim_{R^m_{N_i} \to r_{\max}, A^m_{N_i} \to t_{\min}} I^m_{N_i} = G^m_{N_i} \tag{4}$$

The content of the formulas (1 - 4) can be interpreted as follows: the timely implementation of initiatives in minimum time allows to fulfill the key performance indicators at the target (maximum) level, which leads to the implementation of the strategy. The main task of the implementation of the function (3) in achieving the objectives is to achieve the corresponding extreme values $R_{N_i}^{m} \to r_{\max}, A_{N_i}^{m} \to t_{\min}$ by elements of the equation due to automation with the use of IS and virtualization of the production environment.

3. Review of the Literature

A large number of works are devoted to the topic of assessing the production efficiency and the role of information systems in production, but it should be noted about the coverage, as a rule, a narrow, specialized range of issues within local problems.

In [4] the results of research on the effectiveness of the lifecycle stages of the industrial products are presented. That is, only one of the three lifecycle functional areas of the enterprise is considered: business model, production and product. Mathematical models of the management efficiency function and management index were developed. Functional, informational and simulation modeling of production processes was carried out. By the example of technological preparation of production, the methods of quality assessment and efficiency management are presented. The application of the developed models, methods and composition of the new IS is shown.

The standard [5] is designed to assess the key technical and economic indicators of manufacturing operations management. The standard contains a conceptual framework for the definition, formation, use and exchange of key technical and economic indicators for manufacturing operations/process management (MOM), regardless of the specific branch of production for industrial sectors with continuous, batch and piece production. A feature of the standard is the consideration of all levels of the functional model of production, in which indicators are defined as strategic results, subjected to quantitative assessment of measurements, characterizing the most important factors for the success of the enterprise, are very important for understanding and improving the production indicators both in terms of the prospects for creating economical production in recycling, and to achieve strategic corporate objectives. The standard does not consider the connection with the IS in achieving the goals of the enterprise.

Most fully the question of the relationship of the three components of modern production in terms of a combination of business and production model considered in the standard [1], but also without assessing the impact on these models by the IS dynamics.

In [6] the author presents the definition of the Third Industrial Revolution as a complex multidimensional phenomenon. Its key features are specified: transition to renewable energy sources and raw materials, mass implementation of additive technologies and network production systems, digital basis for fixation and transfer of information, formation of horizontal production and consumer structures, solidary forms of economic relations. The basic groups of innovations in the energy, raw materials, technological, organizational and economic sections are characterized.

4. Materials and Methods

4.1. Key Performance Indicators

Organizational management has passed a thorny path from the ideas of scientific organization of labor in the early twentieth century to modern complex multistage models of organizational development and formed for each stage the main indicators of activity. The basic models of development of the organizations which have found wide circulation now consider development of the organization through a prism of 5–7 crises in model L. Greiner, or 10 states of the organization from origin up to elimination on model I.Adizes [7].

Taking into account the 11 models of basic strategies [8] and 10 states (stages of development) of the organization, its strategy can be one of the 10x11 matrix elements, in turn, each element has certain KPIs.

The article proposes to identify baseline indicators in four perspectives, which allow to assess the impact of IS on the implementation of the strategy. To do this, Figure 3 shows the complex life cycle of the product, production and business logic (operating activities of the enterprise), the corresponding IS and integration links between the three models of LC with the corresponding performance indicators (Table 1).

Table 1
Key performance indicators

Indicator	$I_{N_i}^m$	Measurement unit	P_N	Key ability SMS	Description of the indicator	IS, which affects the indicator
Production productivity	$I_{F_i}^1$	un. /h.	F_i	Productivity	Number of products per unit time (hours, change, day, …)	CAM, ERP
Overall equipment efficiency	$I_{F_i}^2$	dim. -less	F_i	Productivity	Calculated as the product of three components: availability, productivity, quality.	CAM, ERP
Resource efficiency	$I_{F_i}^3$	кVt/un., l./un., м^3/un.	F_i	Productivity	The amount of resources (electricity, steam, gas, water, etc.) required to produce a unit of output.	CAM, ERP
Money circle	$I_{F_i}^4$	day	F_i	Productivity	Characterizes the efficiency of cash flow (formula 5)	ERP
The pace of new product development	$I_{O_i}^1$	day	O_i	Adaptability	The time required to bring a new product to market is estimated	CAD, CAE, CAM
Response time to changes in external and internal conditions	$I_{O_i}^2$	day	O_i	Adaptability	The time required for the transition to new technologies or environmental conditions is estimated	ERP
Execution of the production schedule	$I_{O_i}^3$	%	O_i	Adaptability	The percentage of time during which production maintains the production schedule.	CAM, ERP, SCM
Production cycle efficiency	$I_{O_i}^4$	dim. -less	O_i	Adaptability	Characterizes the efficiency of production taking into account losses according to the methodology of lean production (formula 6)	CAM, ERP, SCM
Indicator of consumer value of proposition	$I_{C_i}^1$	dim. -less	C_i, D_i	Quality	The indicator describes the product (goods) in terms of three components: characteristics (functionality, quality, price, service life), image of the manufacturer, staff qualifications (availability, feedback), (formula 7)	ERP, CRM
Possibility of recycling	$I_{O_i}^5$	dim. -less	O_i	Stability	Recycling as a concept of lean production and environmental protection	-
CO_2 emissions	$I_{O_i}^6$	tona	O_i	Stability	The efficiency of production in terms of environmental pollution and environmental safety is assessed	

Efficiency of logistics	$I_{O_i}^7$	кVt/un., l./un., м³/un	O_i	Stability	The efficiency of logistics is considered in terms of the use of resources for transportation per unit of output.	SCM
Productivity	$I_{D_i}^1$	man.hour./ unit	D_i	Productivity	The number of hours worked by workers required to produce a unit of output.	ERP

All indicators can be divided into four major groups, which correspond to the prospects of the BSC. It should be noted that in each perspective the number of indicators is constantly increasing, due to their improvement and detail, which becomes possible with the introduction of IS and access to data that may previously have been unattainable in real time.

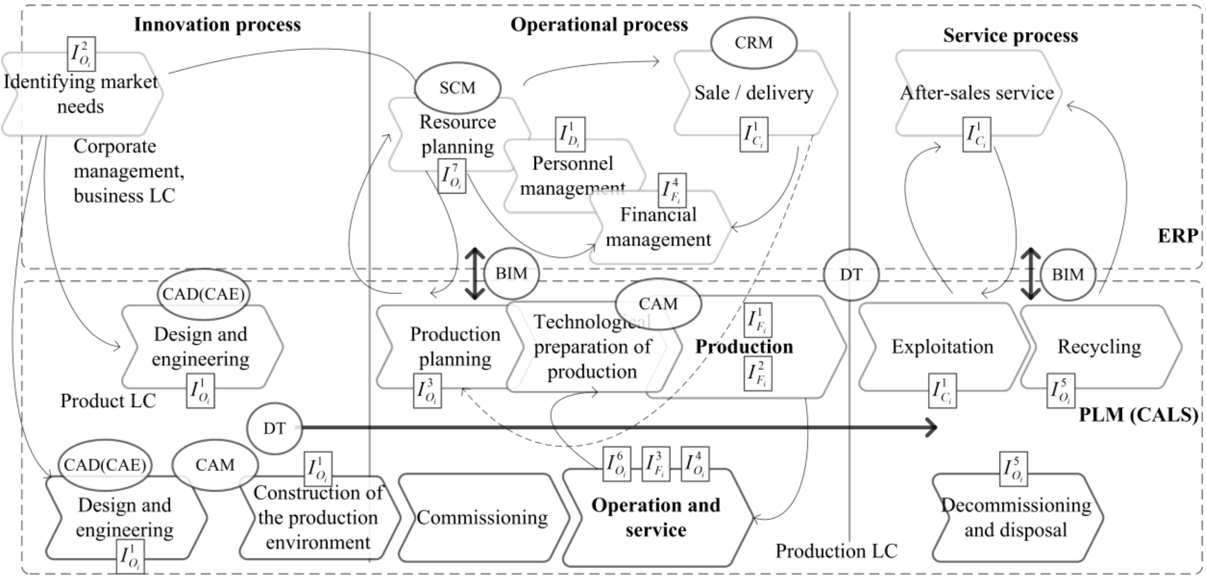

Figure 3: Product, production and business logic life cycle

However, from a practical point of view, to simplify the study, it is possible to use basic complex indicators, for example, for the financial perspective, it may be - the cash cycle, which characterizes the effectiveness of cash management (5):

$$T_{MC} = T_{MI} + T_{IP} - T_{CR};\quad \lim_{T_{MI}\to\min,\, T_{IP}\to 0,\, T_{CR}\to T_{MI}} T_{MC} \to \min, \tag{5}$$

The production perspective, or the perspective of internal processes, can be assessed using the manufacturing cycle efficiency (6):

$$MCE = \frac{T_P}{T_P + T_{QC} + T_{MP} + T_{D/S} + T_{ER}};\quad \lim_{T_{QC}, T_{MP}, T_{D/S}, T_{ER}\to 0} MCE = 1, \tag{6}$$

The customer perspective is described by a complex indicator of the consumer value of the proposition (7):

$$f:(F_P, Q_P, P_P, S_L, S_Q, A_E, T_R) \to I_{C_i}^1;\quad \lim_{F_P, Q_P, T_R, S_Q, A_P, \to \max,\, P_P, T_P \to \min} I_{C_i}^1 \to \max, \tag{7}$$

It should be noted the large number of studies and standards in performance management, for example, in manufacturing is widely used standard [5], detailing each stage of production in terms of its efficiency.

Thus, the considered key indicators allow us to assess both the effectiveness and efficiency of production and enterprise management.

To analyze the impact of IS on performance, it is necessary to consider modern production, which is based on CALS technologies and the concept of the Internet of Things.

4.2. Smart Manufacturing and IS Support

"Smart production", along with the "Industrial Internet of Things", is the basis of Industry 4.0 (Industrie 4.0) - the German government's program for the development of high technology [9]. The main key indicator of the implementation of the program Industry 4.0 - one hundred percent transition to automated production, in which the management of product LC is carried out in real time, taking into account internal and external influences.

As the concept of "smart manufacturing" is at the stage of formulation and formalization, there are also non-standardized classifications of its types, one of which is used in the seventh framework program of the European Council for Scientific and Technical Cooperation, dividing factories into three main types [10]:

1. Digital production. The main tasks of digital production are the development of product models using digital design and modeling tools, which begin to be used in the initial stages of research and development, and end with the creation of "digital layout" (Digital Mock-Up, DMU), "digital twin" [11], a prototype, the release of a small series or individual products customized to customer requirements. The main information systems and technologies of digital production include computer-aided design (CAD): CAD / CAM / CAE; PDM; PLM product lifecycle management software; machines with numerical program control; equipment for 3D production and other additive technologies.

2. "Smart" production. "Smart" productions carry out serial production of products, maintaining the maximum flexibility of production due to the high level of automation and robotics of production. Automated control systems of technological and production processes (ASTPP, PLM) are widely used. Industrial Internet of Things technologies ensure the interaction of equipment in production processes. Production and technological equipment, systems and technologies of enterprise management are equipped with sensors and means of communication that work according to Internet exchange protocols, capable of producing products with minimal or no participation. In connection with the transition to automated control systems for technological and production processes with extensive use of sensors and communications, there is a need for systems of accumulation and "intelligent" information processing, structured and unstructured data of large volumes and diversity, which is solved by tools and technology concepts (Big Data, BD) [12]. Key ISs and smart manufacturing technologies include process control systems; advanced planning and management of production orders (Advanced Planning and Scheduling, APS); Manufacturing Execution System (MES); Industrial Internet of Things (IIoT); Big Data technologies.

3. Virtual production. A virtual factory is a network of digital and "smart" industries, which includes suppliers of inventory, services and customers, consumers of enterprise products. To perform direct and reverse integration management functions: supply and distribution chains, as well as planning and distributed production, virtual enterprises are undergoing reengineering and implementation of automated enterprise management systems ERP, MRP, MRPII, CRM, SCM, ECM (Enterprise Content Management) - management content (content, data, information) of the enterprise, WF (Work Flow) - workflow management (task management systems), DF (Document Flow) - data flow management (electronic document management systems). With a high level of integration in the implementation of these systems, they allow you to design and use a virtual model (DT) of all organizational, technological, logistics, production and other processes of the enterprise, including interaction with suppliers and consumers.

5. Experiments

To analyze the impact of IS on enterprise development by assessing key performance indicators, the main complex indicators were considered under four perspectives (табл.2).

The first industrial revolution increased labor productivity 10-20 times through discoveries and inventions in various industries: weaving and spinning machines in light industry, lathes and milling machines in metallurgy, agricultural machines.

The mechanization of formerly manual production reduced the time to create one car from 400 to 75 man-hours during the second industrial revolution.

Table 2
Dynamics of key performance indicators in the fourth industrial revolution

Indicator	Components of the indicator	The dynamics of the indicator on average	IS
$I^4_{O_i}$	T_P	↓ (30%)	PLM + ERP
	T_{QC}	↓ (7%)	IoT
	T_{MP}	↓ (40%)	PLM + ERP
	$T_{D/S}$	↓ (25% простої, 35% запаси)	ERP, SCM, CRM
	T_{ER}	↓ (50%)	PLM
$I^2_{F_i}$	A_E	↑ (25-40%)	PLM
	$I^1_{F_i}$	↑ (31%)	PLM + ERP
	Q_P	↑ (24%)	PLM + IoT
$I^1_{C_i}$	Q_P	↑ (57%)	PLM+IoT+CRM
	P_P	↓ (25%)	PLM + ERP
	T_R	↓ (34%)	PLM
$I^4_{F_i}$	T_{MI}	↑ (20-40%)	PLM + ERP
$I^1_{D_i}$	-	↑ (50%)	PLM + ERP
$I^7_{O_i}$	-	↓ (80%)	SCM + PLM
$I^1_{O_i}$	-	↑ (50%)	CRM+CAD|CAE

Conveyor production has allowed factory owners to reduce the hiring of low-skilled workers. For example, the reorganization of the Ford factory in 1921 allowed him to lay off 25% of workers and replace them with conveyor processes.

The concept of the third revolution shifted the profit center from the stages of production to R&D centers, development and design. A classic example was the uneven formation of added value in the chains of design - creation and marketing - assembly. There was an increase in labor productivity and, as a consequence, a reduction in blue-collar workers directly employed in production. From the point of view of corporate managment, traditional centralized business models are being replaced by distributed structures with horizontal interaction and project management principles. The results of the impact of IS and information concepts - the main drivers of the fourth industrial revolution, such as the industrial Internet of Things, digital twins, on the performance of enterprises are presented in Table 2 [13].

6. Results

The main goal in the first and second industrial revolutions was labor productivity, which increased in the range of 500–1000%, which was caused by radical changes in production technologies due to fundamental discoveries in science and technology (Fig. 4, item 1). The third industrial revolution shifted the focus to research and development, based on IS and specialized software. The increase in labor productivity is due to the reduction of production time, which becomes automated and integrated with the design and calculation systems, but it should be noted a decrease in the intensity of productivity growth to 100% (pos.2).

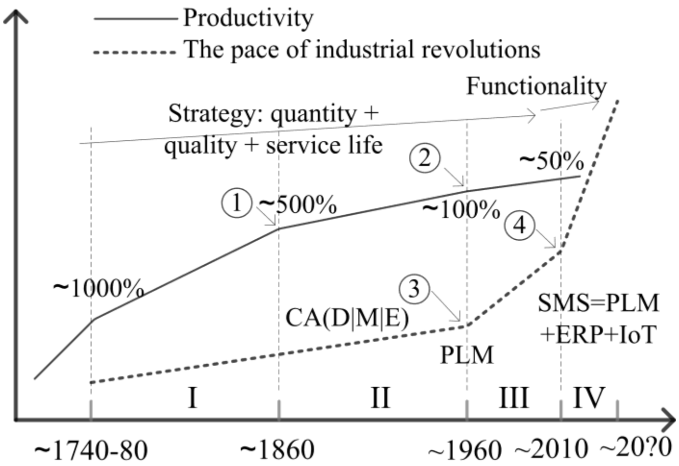

Figure 4: The pace of industrial revolutions

The transition to the fourth industrial revolution also led to increased productivity, but at a slower pace. This trend can be explained by the strategies that prevailed during the industrial revolutions, so if the first and second revolutions were focused on the number of products with quality control and service life, the third industrial revolution has already begun to consider the consumer not only in terms of satisfaction its need for the product as such, but also in terms of functionality. The fourth revolution has retained this strategy, but with greater capabilities for data processing, virtualization, rapid restructuring and quality control through artificial intelligence, allows you to take into account almost all the wishes of consumers, receiving real-time feedback.

Formalized performance indicators (Table 2) can be used as a basis for assessing the dynamics of enterprise development and the impact on this dynamic of both existing and future IS. The acceleration of the industrial revolutions is obvious: almost a century passed between the first and second revolutions, the same period of time was needed for the third revolution, and the term "fourth industrial revolution" began to be used in scientific and business circles 50 years after the third. The widespread use of IS was the impetus for accelerating the pace. The next revolution will be the result of the transition to radically new principles in computational processes and the widespread use of neurosynaptic and quantum systems.

7. Discussion

The influence of IS on the pace of industrial revolutions is interesting from a practical point of view. The period of 250-270 years, during which three and the fourth industrial revolutions took place, can be divided into two major stages: the period before the emergence and intensive development of IS, which is characteristic of the first and second industrial revolutions, and the period from the third revolution - the era of computer science and computer technology. It is obvious that the development of IS, advances in artificial intelligence have twice accelerated the pace of new industrial revolutions. The pace of the first two revolutions was determined by breakthroughs in the basic sciences of the time: the invention of the steam engine, electricity and the possibility of its transmission, etc., which took place slowly. The era of computer technology has dramatically changed the state of affairs, and the first were CAD, CAE, CAM systems, which accelerated the design and development, and in combination with PDM and MRP systems allowed to increase overall productivity (Fig. 4, item 3).

The development of the CALS and PLM concept allowed to combine all production processes in a single information environment, and the combination with ERP systems allowed to develop enterprise management strategies based on the triad Business – Process – Product (Fig. 4, item 4). The concepts of Digital twins and the industrial Internet of Things allowed to bring to a new level of data management in almost real time and significantly increase performance (Table 2).

The advent of the fifth technological revolution will obviously be determined exclusively by advances in IP, namely artificial intelligence and big data in order to respond quickly to changes in production and business environments. Perhaps the fifth industrial revolution will be a precursor to the technological singularity.

8. Conclusions

The results of research and analysis of trends in enterprise performance (Table 2, Figure 4) allow us to make conclusions about doubling the pace of industrial revolutions since the emergence and widespread introduction of IP while reducing the growth rate of productivity.

The main directions of transformation of modern production are determined by three global technological trends: network integration, intellectualization and flexible automation.

The next technological revolution will be determined solely by the development of data science and the transition to new principles of data processing, such as the use of neurosynaptic and quantum computers.

Scientific novelty of the study lies in the formalization of key performance indicators of enterprises, mathematical formalization of the system of balanced scorecard and the definition of IS, which affect the key performance indicators and the nature of this impact. It should be noted that for the first time the following elements are considered on the same plane:

- Models product, business logic, production processes LC
- Key performance indicators to assess the effectiveness of these models
- IS at all stages of models LC
- The relationship between these elements

The practical value of the study lies in the possibility of implementing a balanced score card system in relation to IS and models LC, which are integrated into a single management system.

Prospects for further research. Obviously, defining the indicators of the fifth industrial revolution, the main trends and concepts that will determine it – an open question, and can logically develop the ideas and results of the study.

9. References

[1] Lu Y., Frechette S., Morris KC. Current Standards Landscape for Smart Manufacturing Systems. U.S. Department of Commerce. 2016. – 39 P. http://dx.doi.org/10.6028/NIST.IR.8107

[2] Niedermaier A., Bäck R. ALLPLAN. Short course BIM. Theory and practice. ALLPLAN GmbH Muenchen. 2018. 450 C.

[3] Kaplan R., Norton D. Balanced Scorecard. From strategy to action. - 2nd ed., corrected. and additional / Per. from English. M .: CJSC "Olimp-Business", 2006. 320 p.

[4] P.M. Pavlenko, O.V. Zaritsky, A.O. Khlevny. Information technology for managing the efficiency of industrial production. Chidno-european journal of advanced technologies. - Kharkiv: PP "Technological Center". - 2015. - No. 1/2 (73). – P.24–30. DOI: 10.15587/1729-4061.2015.36070ISO 22400-2:2014. Automation systems and integration — Key performance indicators (KPIs) for manufacturing operations management — Part 2: Definitions and descriptions. 60 P.

[5] L.G. Miller. Innovative perspectives of the third industrial revolution: economics, energy, ecology. Marketing and management of innovations. 2016. No. 4. P.342–352.

[6] Adizes I. Organization life cycle management. MIF, 2014. 512 p.

[7] Thompson A., Strickland J. Strategic management. Concepts and situations for analysis. Ed. House "Williams", 2006. - 928 p.Germany. Industry 4.0. Digital transformation monitor. European Commission, 2017. 8 P.

[8] W. MacDougall. Industry 4.0. Smart manufacturing for the future. Germany Trade & Invest. 2018. P. 40.

[9] A. Parrott, L. Warshaw. Industry 4.0 and the digital twin. Manufacturing meets its match. Deloitte University Press. 2019. P. 20. URL: Industry 4.0 and the digital twin technology | Deloitte Insights.

[10] Thomas E. Fundamentals of Big Data: concepts, algorithms and technologies. Publisher: Balance Business Books, 2018. 320 p.

[11] The fourth industrial revolution. Targets for the development of industrial technology and innovation. Information materials. World Economic Forum. – 2019. – P. 48.