Industry 4.0 and the necessity of a new quality human capital

Trifon Stefanov[1], Stefan Stefanov[2]
Institute for Systemic Economic Engineering, Sofia, Bulgaria[1]
Foundation "Informational Technologies and the Future of Economic Science", Sofia, Bulgaria[2]
trifon.stefanov@isee.bg

Abstract: *Humanity enters Industry 4.0. It is characterized by the emergence of numerous innovative technologies that should be produced in "smart" factories. However, this presents the entire Western world with a problem. Talking about the industry for machines, we immediately talk about machine engineers who power this industry. However, in the West, the crisis with this type of personnel is severe because of our previous ideology – "Knowledge Economy" which diverted many of the finest young people towards social science specialties and above all, those related to economics and management. Therefore, the West, is tasked with creating a new quality industry for machines without the engineering personnel to secure this process.This report presents a new approach to bring back the previous and well-deserved prestige of the all-important engineering profession through a fourth and final engineering wave in the development of a holistic business model ontology, a wave that will also generate a new quality of systemic economic engineers – the necessary engineering capital for realizing Industry 4.0.*

Keywords*: PRESTIGE, ENGINEERING WAVE, ENGINEERING KNOWLEDGE, DISRUPTIVE INNOVATION*

1. Introduction

For us, engineers, it is a well-known fact that the world we live in would not be as we know it today without the enormous advances of the industry for machines[1,2]. It is perfectly clear that today, the industry for machines represents the basis for the operation and development of all other industries. If some unknown force suddenly wiped out all machines in our contemporary world, this would lead to a devastating calamity comparable to a nuclear war.

The fact is that the modern world owes its level of development precisely to the industry for machines. But it would be impossible to establish, maintain, or develop the industry for machines without the existence of a huge multitude of engineers. This status of the industry for machines as leading in the development of all other industries means that engineering positions must be of the highest level of importance and be desired by the most qualified young people in the modern world.

And while this was the case for the majority of the 20th century, in the 21st century this significance and hence prestige have been questioned. The technical universities in the Western world find it increasingly difficult to fill their student quotas, while the industry has been experiencing "acute hunger" for engineering personnel. At the same time, we observe huge growth in all kinds of socio-scientific professionals and, above all, professional economists.

With this concept paper, we will briefly outline the causes of the shocking loss of prestige of the engineering education, but most importantly, we will present a concept for a Fourth engineering wave in the development of the fundamental scientific knowledge of economy, which aims first, to reorient the population back towards the engineering profession and second, create a new generation of machine engineers called systemic economic engineering – the new quality human capital necessary for Industry 4.0 to become a reality.

2. The past, the present and the fourth engineering wave

The state of the engineering education at the beginning of the 20th century and the three engineering waves in the development of the fundamental scientific knowledge of economy

By 1903 the United States of America and Europe were producing thousands of engineers per year, compared to the insignificant number of business personnel (about 30 people) [1, 2]. The engineering profession was particularly celebrated during that period due to the fact that most Western countries were in the process of industrialization, with the U.S.A. at the forefront of this process. Many famous engineers stood behind the industrialization of that time. But optimizing the management of all these enterprises for machines required the development of a new type of knowledge to complement the technical skills of engineers. A necessity emerged for knowledge of the principle set up and way of functioning of the enterprise for machines, which would derive universal approaches to management. Such knowledge — towards the end of the 19th century — was absent. The realization of the absence of such understanding gave rise to the *First engineering wave* in the development of the fundamental scientific knowledge of economy[3].

This wave is associated with the names of the engineers Henry Towne and Frederick Taylor, two prominent members of the American Society of Mechanical Engineers (ASME). Henry Towne reached the conclusion and declared in his work "The Engineer as Economist" (1886) that *"(Shop management) should come from those whose training and experience has given them an understanding of both sides (viz.: the mechanical and the clerical)... **for the reasons above indicated, particularly from mechanical engineers.**"* [3] The First engineering wave creates, develops, and disseminates knowledge of operational modeling of the production processes in an enterprise.

The First engineering wave is followed by another two. The Second engineering wave of development of the fundamental scientific knowledge of economy covers the 1930s, 40s, and 50s. It involves the creation, development, and dissemination of knowledge of production management focused on quality. It is associated with the names of the US engineers Walter Shewhart, William Deming, and Joseph Juran.

By 1950, the number of engineering graduates compared to business and economy graduates was almost equal, but still in favor of the engineers. Dozens of people were fighting for a single place

[1] **Machine** is a broad term – an object that transforms one kind of energy into another. This includes all electrical, automotive, aerospace, etc. machines as well as the machines that are used to manufacture all other machines.

[2] **Industry for machines** - the multitude of enterprises providing machines and spare parts to all industries as well as the multitude of enterprises providing services for those machines.

[3] The knowledge about management of the enterprise processes is fundamental for the knowledge about management of the enterprise economy.

in the technical universities, and the West held a "comfortable" leadership position in a geopolitical plan.

The Third engineering wave covers the 1970s, 80s, and 90s. It involves the generation, development, and dissemination of knowledge of computer-integrated modeling of the sales processes, manufacturing processes, and manufacturing supply processes.

The key concepts for this knowledge are MRP I (Material Requirements Planning) and MRP II (Manufacturing Resource Planning). MRP I refers to knowledge of computer-integrated modeling of the sales processes, manufacturing processes, and manufacturing supply processes without taking into account the production capacity of the enterprise. MRP II refers to the same type of knowledge; however, it also takes into consideration the production capacity. The Third engineering wave of development of the fundamental scientific knowledge of economy stems from the work of two IBM engineers – Joseph Orlicky and Oliver Wight.

The purpose of all three engineering waves was to address the deficit of knowledge of the management of the economy of the enterprise for machines. Even though they provided extremely useful practical solutions, they had not reached a holistic knowledge of management; holistic knowledge, which consisted of unified theory and terminology about the principle set up and way of functioning of the enterprise for machines. It is not clear why American engineers abandoned that goal. The emergence of ERP, the successor of MRP, should have been a step in this direction, but by that time the positions of "ideologues" who affected the direction of development had become the representatives of the different economic schools. They integrate various "business" modules to the classic MRP system. However, this approach leads to the significant departure of the functional constructs of all modern ERP systems from the cognitive universalism, which is inherent in the functional construct of every pure, application-free MRP system.

Nevertheless, it is precisely the three engineering waves and the serious achievements of engineers that gave rise to the United States as a world economic power, as well as the "economic miracle" of Japan after World War II.

The state of the engineering education today

In recent years, we have observed a huge "outflow" of students from technical universities in the West. An outflow, that is paradoxical, as it is the engineering profession that allowed the Western world to become a world leader. For technical universities, it has become increasingly difficult to fill their quotas of engineering majors due to a lack of candidates. According to data for 2020 at the Technical University of Sofia, the enrolled number of students is only 50 % of the university's total capacity, even though the entry requirements are as low as possible (admission in the program is dependent upon a matriculation exam in Bulgarian language). [4] This is not an isolated case and unfortunately, it is not only happening in Bulgaria. It is a fact throughout the Western world. Even technical universities in countries with rich manufacturing history, such as Austria and Germany, cannot fill their universities' capacities. Why do we say the Western world? Because in the East - China, Japan, and South Korea - the situation is rather different, as shown in Figure 1.

Meanwhile, the Western industry is experiencing an "acute hunger" for engineers and technical specialists. Therefore, we need to ask the question *"Which majors related to the management of the real industry do students pursue?"* The answer is the disciplines related to economic science - *Economics, Business and Management, Entrepreneurship*, etc.

In the United States during the 2018-2019 academic year, 426,000 undergraduates graduated with a Business and Economics major, and only 190,000 undergraduates graduated with an Engineering major. In the EU, the situation is no different: 459,000 graduates with a Business and Economics major and 280,000 with an Engineering major [5] [6]. The quality of incoming students in the engineering majors is also questionable. In 2004, for every 100 applicants, only 20 were admitted to the TU-Sofia, while in 2021, there was no competition whatsoever [7]. And as we know, quality is found in the competition. As of today, in the Western world, the number of undergraduates in business and economics disciplines has increased by a factor of 10 since 1950 and engineering only by a factor of 3. Perhaps the Western world's loss of leadership in the global economy to the advantage of China is not accidental either.

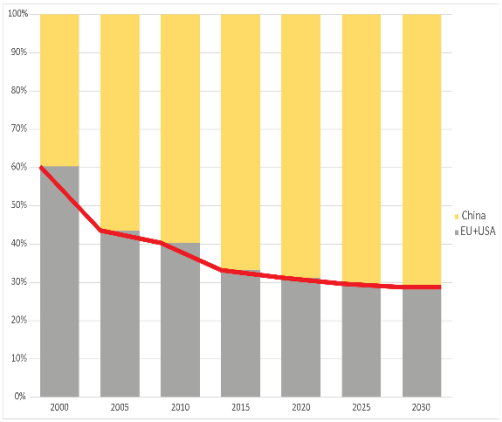

Figure 1. The trend of development of engineering personnel in the Western world and China.

Causes of the loss of prestige in the engineering education

The reasons for the loss of interest in the engineering field to the benefit of the economic field are numerous. The very word "Management" in the Business Management degrees gives the impression that it provides students with high-quality management skills and abilities. Indeed, it is a fact that an economics degree is required to undertake a managerial position. Another reason is the fact that an engineering degree is much more difficult to complete than an economics degree since economic science lacks uniform theory, terminology, and systematic upgrade of knowledge.

However, there are also more global reasons, such as the political ideology of the *knowledge economy* adopted by the West between 2000-2010. According to the Lisbon Strategy, the countries in the West should *"get rid of the outdated manufacturing and to focus on innovation,"* and above all, focus on the services sector – financial services, legal services, and consulting services for "effective management of the economy". Thus, candidates began to shift from engineering professions to a range of social science professions, especially professional economics, and we can observe this decline as shown in Figure 1.

This is all the more unwise because by giving up the industry for machines and the development of numerous and capable engineering professionals, Europe and the United States are voluntarily giving up their geopolitical leadership position. Furthermore, it is becoming more and more evident how they are losing their advantage in innovation and even worse - becoming extremely dependent on China's industry for machines. A fact that was made clear during the "COVID 19" crisis. What does the future hold? The cultivation of countless social scientists and, above all, professional economists at the expense of engineering specialists will lead the Western world to the inability to maintain and develop its current industry for machines, which would eventually lead to industrial collapse. But why can't we rely on modern economists to create, develop, and disseminate practically effective scientific knowledge for the management of the existing industry for machines?

Our in-depth studies of the numerous parts of the modern fundamental scientific knowledge of economy show that the most significant ones (from a practical point of view) are: knowledge of accounting, knowledge of productivity and quality management,

and knowledge of production planning and control by utilizing the MRP algorithm. The first was the work of a monk, and the other three were the work of American engineers. Among these, and all other parts of the fundamental scientific knowledge of economy, there is a lack of unified theory and terminology that would allow graduates of this field to speak a common managerial language. For comparison, the state of medical science was similar before the introduction of the systemic anatomical and physiological model of the human body. This means that in the age of digital information technology, the fundamental scientific knowledge of economy is still at a scholastic level of development, compared to the level of development of the fundamental scientific knowledge of medicine. A fact that is reflected in numerous quotations from the great engineers before us:

Henry Towne, 1886: *"(Management of works as a science) is unorganized, is almost without literature, has no organ or medium for the interchange of experience, and is*

without association or organization of any kind.";

Oliver White, 1981: *"…but where in our manufacturing economy is a school on how to run a manufacturing business in all of its facets? What about the subject of manufacturing itself? … There is not even a well-defined body of practical knowledge on the subject. There are virtually no college textbooks that address the subject from a practical viewpoint."* [8]

What about today? Our survey of economics students from business universities has shown that even when allowed to use specialized literature economics students are incapable of providing a uniform explanation of the objective meaning of terms such as *economy* and *economic science*, *goods* and *service*, or explain the principle setup and way of functioning of an enterprise for machines. One disregarded reason for youth unemployment lies precisely in the fact that our educational system produces graduates who are incapable of meeting the demands of the labor market, both in terms of professional orientation and in terms of the quality of their preparation.

Today we are witnessing how after enrolling in economics and business majors, Europe's youth with the greatest potential do not receive practically useful knowledge for managing the real industry. It turns out that the European educational system has been turned into a machine for intellectual and professional distortion of its most valuable human resources. It sounds absurd, but this is a fact. A fact, which presents a grave issue for the future of the European world.

A concept for a Fourth engineering wave in the development of fundamental scientific knowledge of economy

Today we live in the age of the so-called "Industry 4.0". An age when many new technologies are expected to emerge and be produced in "smart factories". This poses a serious problem for the entire Western world, namely that modern economics education does not provide practically useful knowledge for re-engineering already existing enterprises, or for creating entirely new ones. At the same time, a huge number of young people are directed precisely towards an education in economics in search of this kind of knowledge. Unfortunately, it is not possible to rely on the elder generation that created the vast industry for machines of the West, as these people are either retired or no longer among the living. The currently existing huge shortage of engineers and technical specialists is of no help either. Thus, the Western world is faced with the task of creating an industry for machines of a higher quality without the know-how for this process and without sufficient engineering personnel to fulfill it. This is a prerequisite for a huge division between the West and countries like China – where the specific knowledge is also missing, but their enormous engineering armies and models derived from practice, which they duplicate with phenomenal speed have already earned them the title of "new technological leader".

This means that we, the engineers, especially those at the head of the engineering organizations of our Western World, need to take cardinal measures responsibly and quickly in order to return the interest, and hence the prestige, in the engineering education and to direct more and more young people back towards it [9]. This can be realized through a Fourth engineering wave in the development of fundamental scientific knowledge of economy. A wave that would complete the work of all the great engineers before us and would consist of the creation, development, and above all, dissemination of a new class of digital technologies for managerial modeling of the economy of the enterprise for machines. Technologies whose functional construction includes knowledge of a holistic business model ontology based on the economy of these enterprises, which describes their basic structure and way of functioning as a systemic object and subject.

3. The holistic business model ontology based on the enterprise for machines and what's to come

Is it possible to create a holistic business model ontology based on the enterprise for machines?

Perhaps we also would not have arrived at the concept of a Fourth engineering wave if we were not convinced that such a model really exists. One such model, the only one we are aware of, is the result of more than 20 years of efforts by the Bulgarian Institute for Systemic Economic Engineering (ISEE). During all those years, the main goal of ISEE was to prove to the world that a new generation of holistic ERP systems can be created. ERP systems that are currently available on the market (without exception) are built on the basis of a fragmented (scholastic) fundamental scientific knowledge of economy – knowledge that we have repeatedly found to have large functional gaps.

In this regard, the new ERP systems are completely different. Their engineering design is based upon a holistic fundamental scientific knowledge of economy, which provides a clear understanding of the principle set up and way of functioning of each enterprise for machines as a systemic object and subject. This knowledge is available in the form of hundreds of pages of theory and terminology. This difference opens up the possibility for the new ERP systems to entirely outperform the systems that are currently available on the market. This superiority is clearly observed through a direct comparison between the current prototype of the new holistic ERP system created by ISEE and all currently-available ERP systems. All developments made by ISEE were subjected to practical testing in functioning enterprises for machines.

A number of scientific discoveries were made as a result of the testing activity, two of which have the most significance. Both are defined as "cognitive engineering platforms" for understanding of the enterprise of machines as a systemic object and a systemic subject simultaneously. The first cognitive platform provides knowledge for the understanding of an enterprise for machines in its capacity as a systemic object, which exists as a result of the synergy of five functional systems. The visual representation of the cognitive platform created by ISEE for the understanding of an enterprise for machines as a systemic object has the form of a cross and is called the "Industrial Cross" (Figure 2) [10].

The second cognitive platform provides knowledge for the understanding of an enterprise for machines in its capacity as a systemic subject. Within the second cognitive platform, the enterprise for machines is considered as a complete subject, characterized by an inherent, hierarchical system of five types of knowledge, including a system of responsibilities for continuing its own existence. The visual representation of the cognitive platform created by ISEE for the understanding of an enterprise for machines as a systemic subject has the form of a tree and is called "The Tree of Industrial Cognition". The knowledge of the holistic business model ontology is extremely extensive and is not within the scope of the current paper. It is presented in the book "Business Model Ontology: The Basis for Digital Reform of Economic Science".

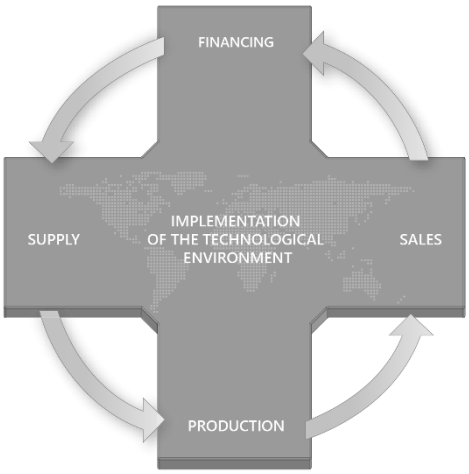

Figure 2. The Industrial Cross

Results of the implementation of the holistic ERP system, bearer of a holistic business model ontology, within enterprises for machines

The developed knowledge of the holistic business model ontology and the holistic ERP system built on its basis have been applied and experimented within mid- and large sized enterprises for machines in Bulgaria and Russia. Once the engineering staff mastered the knowledge and application of the ERP system, they were able to carry out activities within their enterprises at a significantly lower cost of resources and within a shorter period of time than the much more experienced international consultants. Some of the experiments included:

- Large-scale re-engineering of an enterprise for hydraulic cylinders, consisting of more than 500 workers. During the re-engineering process, more than 70% of all workplaces were restructured and relocated. Notably, this process was completed without any suspension or even delay of the production processes.

- Assimilation and modernization of the constructive and technological documentation of axial piston hydraulic pumps and motors and their subsequent implementation in production, technology which had previously never been produced in the Balkan Peninsula. The results of this experiment are spectacular: five young machine engineers, who did not have any prior experience in plant design but were very well versed in the ISEE ERP system, managed to design, build, and ensure the operation of the extensions of the technological environment of two plants. They accomplished all this for the same amount of time and money that foreign consulting companies required to simply update the product documentation.

These, as well as other such results, have proven that after only several months of study of the holistic business model ontology, engineers with no substantial experience in managing enterprises can achieve practical results that even the most renowned professional economists cannot accomplish[4].

Potential outcomes of the Fourth engineering wave in the development of fundamental scientific knowledge of economy

We will try to briefly present the potential effect of the theoretical and practical study of knowledge of the functional construct of the holistic ERP systems and its impact on Industry 4.0.

The people who should consider this knowledge to be of the highest priority and should study this knowledge are engineers, and more precisely machine engineers[5], as the real professionals who create, develop, and manage the industry for machines. This view is in complete agreement with the concept of "The Engineer as Economist" – an idea born in the late 19th century that led to the three engineering waves in the development of the fundamental scientific knowledge of economy, but which has remained incomplete to this day.

The only viable chance for realizing "Industry 4.0 is through the realization of a Fourth engineering wave in the development of the fundamental scientific knowledge of economy. This wave will lead to the finalization of the work of the American engineers, Henry Towne and Frederick Taylor. A finalization, crowned by the emergence of a new generation of machine engineers, which we define as "*systemic economic engineers*" [11].

A *systemic economic engineer* is any professional machine engineer who, as a result of purposeful education, has acquired fundamental and specialized engineering knowledge in a certain field of the industry for machines, and has also acquired theoretical and practical knowledge of the new class of holistic ERP systems. The *systemic economic engineer* - as a result of several months of theoretical and practical study of the functional construct of the holistic ERP system - forms a cognitive potential for managerial modeling of the economy of the enterprises for machines, which is far superior to the one possessed by even the most renowned professional industrial economists. A superiority, which is expressed in the conscious understanding and application of:

(1) knowledge of the principle set up and way of functioning of the enterprise for machines as a systemic object and subject;

(2) practical knowledge for development of highly effective strategies for future economic development of the enterprise for machines with a focus on anticipating the development of its innovation potential;

(3) practical knowledge for the development of highly effective programs for training, retraining, and motivation of the staff of an enterprise for machines – programs that aim toward the realization of the strategies for future economic development of the enterprise for machines;

(4) practical knowledge for auditing enterprises for machines in order to assess the current and future development of their economy and to generate ideas to increase the effectiveness of this development;

(5) conceptual knowledge for the creation and development of a truly effective accounting model of the economy of the enterprises for machines;

(6) knowledge for the management of the cost and quality of a product and the ability to conduct a technological analysis of the process of creating the goods and services sold, while offering different options for implementing this process;

(7) practical knowledge for the development and management of projects for implementation of systems for lean manufacturing (Single-Minute Exchange of Die – SMED) of goods and services sold by the enterprises for machines;

(8) practical knowledge for the planning and management of the execution of engineering and reengineering of enterprises for machines or large parts of them.

4. Conclusion

The Fourth engineering wave in the development of the fundamental scientific knowledge of economy will lead to the emergence of a new generation of machine engineers – *systemic economic engineers* who represent the new quality human capital necessary for the successful realization of "Industry 4.0". .

It is the managerial advantages of the new knowledge of a holistic business model ontology that will bestow huge prestige to

[4] The experiments and some of the results are presented at https://isee.bg/en/.

[5] **Machine Engineer** – a practitioner of machine engineering. Machine engineering is the branch of engineering that involves the design, production, and exploitation of all types of machines. "Machine engineer" is the umbrella term that unites all those engineers dealing with machines, which include: mechanical, electrical, computer, automotive, aerospace, hydraulic, etc., engineers.

the engineering profession, which will naturally attract the young people who want to engage in industrial management. The emergence of *systemic economic engineers* and the shift of the human capital of the Western world back to engineering, the natural environment for cultivating quality executives for the industry for machines, will bring our Western world back to its morally responsible, creative foundations of the early and mid-20th century. The same foundations that made the Western world the technological and economical leader of the whole world.

The success of "Industry 4.0" relies on the successful dissemination of the new quality knowledge for managerial modeling of the economy of the enterprise for machines. This dissemination should first be extended to all technical universities, and subsequently, the knowledge of a holistic business model ontology should become a standard for enterprise management. A standard controlled by the best technical universities of our world.

The responsibility to make all this happen rests upon us, the engineers, and the engineering organizations concerned about both the future of our profession, as well as the future of our world.

5. References

[1] "History of the MBA," MBA Today, [Online]. Available: https://www.mba.today/guide/mba-history.

[2] F. Taylor, in *Научното управление (Scientific management)*, Sofia, Профиздат, 1989, pp. 20-21.

[3] H. Towne, "Transactions of the American Society of Mechanical Engineers, Volume VII," *The engineer as economist*, vol. VII, 1886.

[4] "Рейтингова система на висшите училища в България (Rating system of the Bulgarian institutions for higher education)," Министерство на образованието и науката (Bulgarian Ministry of education and sciense), [Online]. Available: https://rsvu.mon.bg/rsvu4/#/detailed-comparison.

[5] "Digest of Education Statistics," National center for education statistics, [Online]. Available: https://nces.ed.gov/.

[6] "Graduates by education level, programme orientation, sex and field of education," Eurostat, [Online]. Available: https://ec.europa.eu/eurostat/data/database.

[7] Д. Черкезова, "Инженерите са ни важни (Our engineers are important)," Капитал, [Online]. Available: https://www.karieri.bg/news/34329_injenerite_sa_ni_vajni.

[8] O. W. Wight, Manufacturing Resource Planning: MRP II Unlocking America's Productivity Potential, Oliver Wight Limited Publications, Inc., 1981, p. 7.

[9] S. Stefanov and T. Stefanov, "Restoring the prestige of engineering education through a fourth engineering wave in the development of the fundamental scientific knowledge of economy," *European Society of Engineering Education*, 2022.

[10] T. Stefaonv and P. Bachvarov, Business Model Ontology: The Basis for Digital Reform of Economic Science, 2022.

[11] S. Stefanov and G. Velev, Digital reform of Economic Science: Vision for a New Road in the History of the Future, 2022.