Industrial Engineering Studies: Ergonomics Essences in the Systems Approach

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Abstract

Industrial engineering science is developing rapidly with an increasingly broad object of study, richer methods and an increasingly large role in various fields. The development of industrial engineering always synergizes with other scientific and engineering disciplines (especially in the field of automation). Industrial engineering science has been proven to have a role in giving birth to the industry 4.0 phenomenon. Despite all the advantages and conveniences that will be provided by Industry 4.0, there are still negative consequences and impacts that must be faced. No exception to the science of industrial engineering itself. This is where the challenge of industrial engineering science is to continue to study and develop its scientific field. Even though there are influences from changing times and other scientific developments, industrial engineering should retain its uniqueness, namely the focus on studying human interaction with various other components in integrated systems in industry. It is hoped that in the future, industrial engineering can have a role in directing the Industrial 4.0 era to the advancement of science that provides great value for humanity.

Keywords
Industrial engineering, ergonomics, axiology, epistemology and ontology.

1. Introduction

Engineering science was already known by the public in 1900. Production processes that occurred were planning production, selecting, and supplying materials, as well as producing and controlling. The engineering sciences that were developing at that time, such as mechanical engineering, chemical engineering, felt that they did not accommodate detailed definitions of characteristics, characteristics, specifics, or scope (Wignjosoebroto 2009). Industrial engineering is then known to accommodate these needs and is a profession with very dynamic growth (Maynard and Zandin 2004)

The industrial revolution brought change and gave rise to an invention, namely the factory (Samadhi 2012). The conceptual and technological frameworks shaping industrial engineering practice are not only dependent on the practitioner's ability to react and can facilitate operational change. The industrial engineering discipline is less appropriate if it is included in the realm of "engineering" which greatly emphasizes competence in designing based on a quantitative approach (Wignjosoebroto 2009).

Industrial engineering basically states that the object being designed is called an integrated system consisting of integrated from materials to people or equipment, energy, and information. This system consists of specific knowledge that goes hand in hand with abilities. Basic sciences such as calculations, physics, and social sciences will integrate with each other to form principles for designing, analyzing, engineering, predicting, and evaluating the results obtained from systems (Institute of Industrial Engineers 2021). These integrated systems use analytical, processing, and experimental tools to get the performance you need. The expected performance is the efficiency and productivity of the designed system (Samadhi 2012).

The development of industrial engineering, which was originally a discipline that focused on the study and design of work, then developed significantly. The intensity of the study of work that occurs on the production floor (shopfloor) then develops in a macro direction related to the socio-economic area of the industry. These conditions have brought industrial engineering disciplines to no longer have the ability to organize work and design modern work systems (Bailey and Barley 2005).

The integrated system evolution can then be described in Table 1:

Table 1. Integrated system evolution

Object	Component	Knowledge		Performance
Work station	Man, Machine, material	Ergonomy, Psychology, Eng. Economy		Productivity Efisiensi
Manufacture	Man, Machine, Material	Inventory, PPC, Quality Control, OR, Modeling		Quality Cost Delivery
Company	People, Facility Material	Management Social Sciences Behavoiur Science		Return: ROI, IRR, ROE
Supply chain	People, Facility Material	Systemic and integrated		Competititiness
Industrial System	People, material, Infrastructure	Policy, economy		Growth
Real System	People, material, Infrastructure	Social, Ethics, global aprroach		Social Welfare

The rapid development of science will then be studied further. Humans and machines become integrated systems. Sociotechnical systems have been used to optimize human-machine interface systems since the 1940s. The focus for the first three decades was on the system interface between individual operators and their immediate work environment. The conditions that occur then are called micro-ergonomics. Scientific knowledge of human limitations, human-generated maximum capabilities, and other characteristics forms the basis for developing and implementing designs of operator controls, displays, equipment, workspace settings, and the physical environment. These additional designs are used to improve health, safety, comfort, and productivity while minimizing human error through design (Hendrick and Kleiner 2002).

Engineering is a discipline of expertise that is directly related to the fulfillment of human physical needs. Kleiner, 2004 said that macro ergonomics provides a sociotechnical framework for studying macro and micro problems associated with large-scale organizational change. According to sociotechnical systems theory, the personnel and technology subsystems are jointly affected by environmental forces and, as such, the organizational structure should be designed as a function of the joint design of the personnel and technology subsystems.

This article discusses the history and views of industrial engineering science in ontological, epistemological and axiological perspectives. Macro ergonomics then becomes one of the studies in industrial engineering science which is then harmonized with system studies.

2. Literature Review

Philosophy was first put forward by Pythagoras (527-497 BC) who defined that humans have the highest level of wisdom. Socrates (469 – 399 BC) argued that philosophy is a self-reflective review. The definition of philosophy then developed from among experts, so that it was formulated that philosophy relates to logical sentence forms from scientific language, with assessments, and in-depth discussion (Susanto 2019).

Broadly speaking, philosophy has three main areas of study, namely ontology, epistemology, and axiology. Ontology will discuss the rational principle of the actual situation. Epistemological studies are a branch of philosophy that investigates the origin, structure, and methods. Epistemology is also often called the theory of knowledge. The study of axiology is called the theory of value, which is generally viewed from a philosophical point of view. So that philosophy can be used to see about three things, namely: 1. Collection of theories, 2. Outlook on life, 3. Methods of problem solving.

Philosophy and science are inseparable. The two will be substantially and historically related to each other. Philosophy is not only seen as the mother or parent and source of knowledge, but philosophy has become part of the science itself which is also experiencing specialization. (Kaukab 2014).

Ergonomics is a branch of industrial engineering discipline that focuses on human interaction. The perspective of the unity of science, engineering, design, technology, and humans will form a system. Systems that cover a wide range of natural and man-made products, processes and the environment will work together (Karwowski 2005)

3. Methods

The method used by this paper is to develop studies in the form of trends in the development of industrial engineering science from time to time (past, present, and future). The method that will be used in this article is:

1. Collection of literature in accordance with developments in industrial engineering science
2. Collection of literature in accordance with developments from 3 Industrial Engineering Body of Knowledge (BoK) studies, namely (1) operations research and analysis, (2) ergonomics and human factors, (3) safety
3. Collection of data from various search engines
4. Make conclusions from the linkages of the fields studied

The development of science is inseparable from great curiosity, which is accompanied by serious efforts through reasoning, experimenting, perfecting, and daring to take high risks. Philosophy of science plays a role in encouraging scientists and experts to always study and guide how knowledge should be utilized and where knowledge should be developed. Philosophy of science has three main foundations of thinking, namely, (1) Ontology which is an analysis of the object studied by science. (2) Epistemology, analysis of the methods used to construct knowledge. (3) Axiology, analysis of the application and benefits of the findings of the science.

Tabel 2. The framework for analyzing the scientific philosophy of Industrial Engineering

Ontology	Meaning	What can be developed from this science?
	Substance	Why was industrial engineering science developed?
Epistemology	Methodology	How do studies in industrial engineering science synergize with one another? How does the scientific study of industrial engineering respond to trends that are currently developing?
Axiology	Application	What is industrial engineering study for? What is the impact of the application of industrial engineering studies?

4. Data Collection

The term philosophy comes from the word philosophia (Greek) which consists of the words philos (love) and sophia (wisdom), so that it can be interpreted as the love of wisdom. Science or science is an attempt to understand, explain and estimate all the properties that exist in the universe using scientific methods (Okasha, 2002). Philosophy and science are two related things so that in its development it becomes a separate study called the philosophy of science. Philosophy of science has a close relationship with scientific method and provides a simple understanding that philosophy of science is a way to test the assumptions and methods used by scientists in producing knowledge (Prasetyo and Sutopo 2017)

The invention of the steam engine by James Watt in 1750 - 1850 made industrial development even faster. Along with these findings, there have been major changes in vital economic sectors such as the mining, manufacturing, transportation sectors, as well as influencing socio-culture. This rapid development became known as the industrial revolution (Robert 2002). This development can then be described according to the following Table 3.

Tabel 3. Scientific Development of Industrial Engineering in the Industrial Revolution (Prasetyo and Sutopo 2017)

Industrial Revolution I	1750	*Interchangable parts specialization work*	Scientific Management, classical management, and behavior
	1800		
	1850	*Division of work*	
Industrial Revolution II	1900	Standardization Management principles Principles of scientific management *Motion studi* *Gantt Chart, Inventori Control*	
Industrial Revolution III	1950	*Moving assembly line, EOQ* *Statistical Quality Control* *Operation Research, Layout Design*	Science Management
	2000	*Material Requirement Planning*	
		Industrial and System Engineering CAD, FMS *Total Quality management, Lean Manufacturing, ERP*	Integrated system
Industrial Revolution IV		*Supply chain management* *Rapid prototyping* *Mass customization* ….	Global thinking

The characteristics of each era in the development of industrial engineering science are as follows Figure 1.

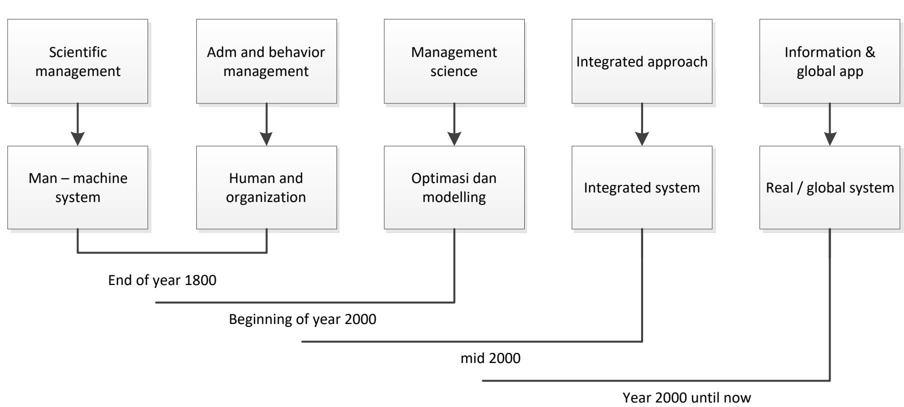

Figure 1. Characteristics of each era of industrial engineering scientific development

Scientific Management

By 1880 engineers becoming increasingly challenged to manage the chaos contained in the factory system. Mechanical engineers were then responsible for maintaining the physical plant, supervising production processes, and designing equipment. Several engineers began experimenting with what is now referred to as organizational design (Bailey and Barley 2005). Industrial engineering in this era still focuses on improving work methods and work specialization. This era is called the era of scientific management. Systematic management developed in this era includes 3 types of schemes, namely (i). Cost accounting system; (ii) production control system; and (iii) wage payment plans (Litterer 1963). F.W. Taylor was a pioneer in industrial engineering who presented the idea of organizing work using management. Its activities, like others, cover topics such as organizing work with management, selection of workers, training, and additional compensation for all individuals who meet standards set by the company. (Rokhayati 2014)

Administrative and Behavioral Management

The major contributions of the behavioral thought movement are providing a deeper understanding of the concepts of motivation, group dynamics, leadership and interrelationship processes within organizations. This study of thought also places workers as individual human beings who have unique characteristics. Workers are a resource that has value because they have a mind and not only as a means of production for the company. (Wiwoho 2017).

Management Science

The industrial engineering discipline is shifting towards developing industrial problems on a large (macro) scale with various studies that lead to quantitative and analytical approaches in solving industrial problems that are increasingly abstract, comprehensive, full of uncertainties and difficult to predict. The industrial engineering discipline continues to develop with various methods and approaches in the realm of analysis and decision-making processes by incorporating risk factors that are often encountered in the world of industry, business, and management.

The industrial engineering discipline begins to open up new understandings and paradigms in the study of engineering/engineering which no longer looks at the industry in technical aspects (controls, displays, and human-machine systems), but also various non-technical issues such as costs analysis, environmental, management, social-engineering, and others (Bailey and Barley, 2005). The decision-making process in solving problems in large-scale industries can no longer be done partially, piecemeal, and linearly; but it must be done with a mindset and lateral action with all kinds of considerations that are multi-dimensional, qualitative, and sometimes require intuitive sensitivity. Industrial problems are not only determined by the exact material sub-system but are also influenced more by the human sub-system with behavior that is more difficult to predict. Industrial problems besides depending on passive factors of production (raw materials, machines, buildings, or other production facilities), will also be heavily influenced by active factors of production, namely humans (both as individuals and working groups) with all kinds of behavior.

The figure in Quantitative management thinking is Von Neumann (1940). The concept of strategic planning is known as The Game Theory, in this theory it examines the level of outcomes that can be predicted from collective activity calculations of behavior and calculations of the impact of various opportunities that exist. The contributions of the quantitative thinking movement are a. Development of complex quantitative thinking techniques as tools in developing decisions and solving business problems b. The use of mathematical models in planning and control processes has given rise to the widespread application of computerized techniques as decision-making tools c. The use of computers in the operations of a business organization starts from the application of this quantitative concept.

Integrated Approaches

In the integrated approach era, the context of the problem is made in the form of a framework with a system methodology that connects different problem contexts with the type of problem-solving methodology that is appropriate for each context. The use of system types as decision makers is the main source of contextual elements. The overall classification of the problem context becomes a synthesis of these two classification elements. (Mariah, Tahir, Aprilliany, Ningsih, and Pratidina 2017)

Jackson and Keys situational context has two elements, namely for the type of system and for decision makers, namely: (Jackson and Keys1984)

1. Contextual Element One: System Type.

Russell Ackoff used the terms engine age and system age to refer to the era associated with the two different types of systems (1974, pp. 2-4). Machine age relates to simple systems, and system age relates to complex systems. Ackoff's terminology can conclude that the problem context includes elements of the mechanical problem context (simple system) or the systemic problem context (complex system).

2. Contextual Element Two: The Decision Maker.

   The decision maker greatly influences the type of solution required and ultimately, the problem solving methodology required to arrive at the solution. The Jackson and Keys criterion used to classify decision makers is whether they are unitary, pluralistic, or coercive with respect to their goals. Decision makers are unified if they all agree on the same set of goals for the system and make their decisions in accordance with these goals.

Soft Systems Methodology (SSM) developed by Peter Checkland in the 60s at Lancaster University in England became one of the results of the integrated approach era. SSM is used as a modeling tool to easily understand problems that will be described in a "real" form, but the trend a few years later has been used as a development tool for learning and meaning activities. The basis of SSM originates from thoughts related to one's participation in a process of finding problem situations and ways to fix them. This participation will certainly cause the person to prefer to understand the expected improvement, feel they own the problem, and commit to change it. SSM is a suitable methodology to assist an organization in clarifying their goals and then designing human activity systems to achieve these goals. (Nugroho 2012)

Based on the elaboration of each era, it can be concluded according to the study of ontology, epistemology, and axiology. Ontology, epistemology, and axiology studies from each era are further examined in the following Table 4.

Table 4. Ontology, epistemology, and axiological studies

	Ontology Studies	Epistemological Studies	Axiological Studies
Scientific management	a. There is a change in the workmanship of the manual system from human labor to a fabrication system b. There is an increase in productivity through the analysis and design of work methods with scientific principles	The method used in this era is observation and observation The nature of this era is operational	There is a discovery about the steam engine, the principle of scientific management, the wealth of the nation
Adm and behavioral management	There is an application of management theory based on planning, organizing, actuating, and controlling activities	The method used in this era is Experiment. The nature of this era is managerial ability	There is the Hawthorne experiment and the principle of management
Management science	The use of a mathematical approach and classical optimization as a method for increasing productivity (optimization)	The method used in this era is synthesis The nature of this era is to look at it from an operational and tactical perspective	The emergence of operational investigations (operation research)
Integrated approach	Cybernetic Approach, Soft System Thinking, Critical System Thinking and Total Intervention System	The method used in this era is the synthesis of a system methodology from the context of the problem and its solution	The emergence of a soft system methodology

5. Results and Discussion

The age of information and global applications began that year. Industry insiders confirm that the software has become very "modular" during this time. The development of high-level computer languages led to the early creation of large libraries of standardized routines that could be combined to produce an almost infinite variety of software-driven product functions. At a time when physical components still mattered in many technical fields, software in the internet age could more easily be transferred around the world quickly and easily, and software components developed in remote locations could be quickly tested and integrated into larger systems. The Internet and advanced information technology have created the possibility of remote, real-time collaboration.

Along with the rapid development of ICT, industrial engineering science is also experiencing development. Institute of Industrial Engineering, a discipline of Industrial Engineering concerned with the design, improvement, and installation of integrated systems of people, materials, information, equipment, and energy. Industrial engineering capability refers to specific knowledge and skills in the mathematical, physical, and social sciences along with the principles and methods of engineering analysis and design to define, predict, and evaluate the results to be obtained from such systems. Each of each focus has characteristics and markers as a manifestation of the development of human needs and methods of thinking in every era. Changes in mindset also affect human needs, which eventually led to engineering (engineering). In a systemic way, knowledge (science) exists first underlies the development of engineering. These three disciplines (science, engineering, and industrial engineering) synergize and trigger new discoveries in one scientific discipline, whereby these developments will influence the development of other disciplines and ultimately re-develop the discipline itself

The Industrial Engineering profession is based on three basic function groups, namely Operational Science, Ergonomics or Human Factors Engineering, and Production Engineering. Broadly speaking, each of these basic functions then forms the Body of Knowledge (BoK) of the Industrial Engineering discipline, which can be explained as follows:

1. Operational Science: science and knowledge related to behavior regulation and management of work groups such as operational research, organizational design, management information systems, economic analysis, etc.;
2. Ergonomics/Human Factors Engineering: science and knowledge related to human empowerment in integral systems such as ergonomics, work design, payroll administration, occupational health and safety, and others;
3. Production Engineering: science and knowledge relating to the design and management of manufacturing processes as well as production planning and control, such as production planning and control, quality control, manufacturing processes, factory layout, and others.

The three basic functions that make up the body of knowledge of the Industrial Engineering discipline consist of engineering science which is typical of Industrial Engineering Science and General Engineering Science. General Engineering Science is a body of knowledge that forms the foundation for all engineering disciplines such as engineering mechanics, thermal science, materials science, electrical science, control science, and fluid mechanics, which are more deeply rooted in natural sciences and mathematics. Whereas Industrial Engineering Science has a broader foundation, for example for Manufacturing Processes it requires the basics of mathematics, chemistry, physics, Material Science, Engineering Mechanics, and Thermal Science. ergonomics requires the basics of human anatomy, industrial psychology, and industrial sociology. Therefore, the roots of knowledge from Industrial Engineering Science are behavioral and social sciences and life sciences

Ergonomics and Human Factors Studies

Ergonomics appeared in the middle of the 20th century, in the first 10-12 years (1949-1961), this study has a slower evolution. The conservative views of the sciences that participated in its formation, which have created their own field of research and are not going to easily abandon the position they have acquired. The decisive part for the solution of this dispute is played by cosmic flights which lead to the association of a number of scientific fields: (biology, medicine, psychology, anthropology, etc.) supports cosmic flight.

This historic moment in the evolution of modern technology means a strong stimulation of ergonomics research, which then spills over to industry and generates public interest, demonstrated through the International Ergonomic Association Congress – IEA), which was founded in Oxford, in April. 1959, as well as the annual congress of the French Ergonomic Society (Société d'Ergonomie de Langue Française - SELF), held in 1963, which had about 350 members in 1986.

HFE's background is the need to find solutions to some practical problems. Such problems are characteristic of the nature of the work of that time - the late 19th and early 20th centuries. Since the nature of work in 2010, a hundred years later, is so different, it makes sense to consider whether the traditional problem formulation to automation systems still holds true today.

Early 20th century scientific management theory (Taylor, 1911) is a good place to start. The goal of scientific management is very practical, that is, to analyze and synthesize work processes to increase labor productivity. To this end, scientific management introduced a set of principles and techniques that are still widely used today, although their origins may have been forgotten. Examples include bottom-up task analysis, temporal and motion studies, and task decomposition. The science-led phase deserves the name proteomics. Later in the century, the original emphasis on efficiency and productivity was supplemented, if not fully replaced, by the need to ensure that people and technology work well together. This demand is not due to changes in people, but changes in technology and the nature of work. These changes were based on technological and intellectual developments around the 1940s, the most famous example of which was the digital computer, or what we call information technology equipment today.

In formulating the theory of scientific management, machines are mechanical in nature and serve well-defined functions such as the manufacture of goods, the production of energy, the propulsion of vehicles large and small. machines as a whole for separate individual tasks, not integrated processing; they are large and thus visible in the sense that people can see (hear or smell) what they are doing; due to the clumsiness of mechanical parts and inertial, they operate at finite speeds; their functions are relatively simple or straightforward because their self-regulating capabilities are limited to those that can be achieved mechanically. That all changed with the advent of the digital computer and related inventions like the transistor and integrated circuit.

Operations research and analysis

Dynamical systems theory (also known as nonlinear dynamics or chaos theory) comprises a variety of analytical, geometric, topological, and numerical methods for analyzing differential equations and iterative mapping. As a theory of mathematics, it should perhaps be seen as a "normal" development in mathematics, rather than a scientific revolution or paradigm shift. Important motivations and ideas have entered this field of mathematics from applied science, and a steady stream of applications driven by recent developments in dynamical systems theory began in the last third of the 20th century. “Sociohistorical” analysis addresses these extra-mathematical influences and explains the confluence of ideas and traditions that took place in Western Europe and the US during the turbulent decade around 1970.

Industrial engineering scientific trends that will come (future)

Industrial engineering is currently experiencing many changes. Some of the influences that give color to industrial engineering science include the following Figure 2:

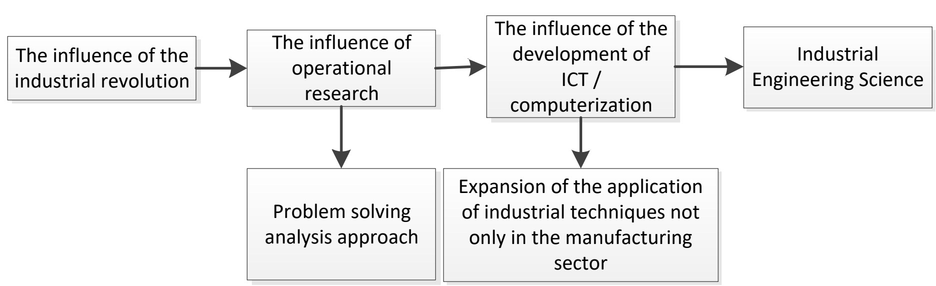

Figure 2. Industrial engineering scientific linkages

The application in axiological studies in the field of industrial engineering requires a number of changes. Industrial engineering is not only focused on system building and modeling. Scientific activities are no less important as a basis for making empirical studies. Industrial engineering today turns to mathematical analysis and laboratory studies to assert its claims of scientific rigor. The irony, however, is that no matter how important mathematics is to scientific practice, it is not sufficient in itself: all science is rooted in empirical observation. In fact, advanced science empiricism usually complements and supports mathematical modeling. The strongest mathematical models of systems are based on a substantive understanding of the phenomena being modeled.

Industrial engineers must also be proficient in the social sciences. This makes industrial engineers better at bridging technology and society. Embracing society doesn't mean industrial engineers have to be social scientists. However, this means that the social sciences must become part of the industrial engineer's toolbox, just as the toolbox currently includes skills such as simulation, computer programming, probability, database design, etc.

6. Conclusion

Industrial engineering science is developing rapidly with an increasingly broad object of study, richer methods and an increasingly large role in various fields. The development of industrial engineering always synergizes with other scientific and engineering disciplines (especially in the field of automation). Industrial engineering science has been proven to have a role in giving birth to the industry 4.0 phenomenon. Despite all the advantages and conveniences that will be provided by Industry 4.0, there are still negative consequences and impacts that must be faced. No exception to the science of industrial engineering itself. This is where the challenge of industrial engineering science is to continue to study and develop its scientific field. Even though there are influences from changing times and other scientific developments, industrial engineering should retain its uniqueness, namely the focus on studying human interaction with various other components in integrated systems in industry. It is hoped that in the future, industrial engineering can have a role in directing the Industrial 4.0 era to the advancement of science that provides great value for humanity.

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Biography

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