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The Roles of Industrial Engineering Education for Promoting Innovations and Technology Commercialization in the Digital Era

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Abstract. Industrial engineering is concerned with the design, improvement, and installation of integrated systems of people, material, information, equipment, and energy. Industrial engineering science and knowledge play a very important role in the development of the industrial revolution. Manufacturing sector which is the work area for industrial engineering is currently undergoing a fourth revolution. Universities play a key role in this development by producing innovations through researches that were done by academics in this digital era. Technology commercialization is required in order to provide commercial value for the development of technology produced by the university. Technopreneurship as an industrial engineering education course is expected to be the bridging system to promote utilization of technology and transfer innovations product from a university.

Keywords: commercialization, digital era, industrial engineering, Technopreneurship

1. Introduction
Industrial engineering is concerned with the design, improvement, and installation of integrated systems of people, material, information, equipment, and energy. It draws upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design to specify, predict, and evaluate the results to be obtained from such system [1].

Industrial engineering science and knowledge play a very important role in the development of the industrial revolution [2]. Step by step of the revolution had passed through the discovery and problems faced both in the community and in the industrial world [3] [4] [5] [6]. The development of the industrial revolution brought an era of very rapid change in scientific advances in industrial engineering [7] [8] [9] [10] [11] [12]. This matter is inseparable from the role of universities as education providers and producers of industrial engineering graduates [13] [14] [15]. Hence, industrial engineering education is highly concerned [16] [17] [18] [19] [20] [21] [22] so that universities can perform their responsibility to form quality graduates who will be armed with the knowledge needed in industrial practice [23]. Thus, universities can support the decisive role of industrial engineers as transmitters and introducers of progress [24].

Manufacturing sector which is the work area for industrial engineering is currently undergoing a fourth revolution [25] [26] [27]. The current revolution is involving new and integrated technologies that
function on huge data transfers [28]. In addition, digitalization in the manufacturing sector has been occurred to enhance the interaction between machine and machine [29] [30] [31] [32]. The advanced digitalization of factories, the Internet, and future-oriented technologies is bringing intelligence in devices, machines, and systems [33] [34] [35]. This causes a reduction in the volume of the role of human labor operators and increases the requirement of high competence in human labor. This is a challenge in the global information age for higher education stakeholders, especially in industrial engineering field, to prepare reliable and quality human resources and be able to compete in facing challenges in meeting the demands of society and industry along with the rapid development of information technology and science [36] [37] [38].

In this digital era, there has been a rapid development of innovations and technology in the industrial sector [39] [40] [41]. Universities play a key role in this development by producing innovations through researches that were done by academics [42] [43] [44] [45]. Hence, universities are considered an open innovation source as a result of the research activities [46] [47] [48]. Many innovation and technology products have resulted from university, for instance, lithium battery technology [49][50][51], electric vehicle [52] [53] and traceability technology [54] [55]. The innovations would be more beneficial if they are followed by commercialization. Technology commercialization is required in order to provide commercial value for the development of technology produced by the university [56] [57].

Technology commercialization is an attempt to move technology into a profitable position [58]. The technology will be developed from basic research through a go-no go system scheme into a point where it can be exploited in either production or consumption activity which provides profit for the inventor [59]. Nonetheless, numerous technology products are unsuccessful to be launched in the market due to the valley of death [60]. This immense obstacle occurs in the intermediate process between technology development and technology commercialization where the funding to lift prototype into the market product is likely insufficient. Therefore there should be a bridging system between technology development and commercialization in order to ensure the commercialization potency of research output does not fall into the valley of death. Industrial engineering education is expected to be the bridging system to promote utilization of technology and transfer innovations product from university into various type of business entity [61]. In this article, we aim to investigate the roles of industrial engineering education to promote innovation and technology commercialization in the digital era.

The remainder of the paper is organized as follows. Section 2 presents the literature review regarding industrial engineering in the digital era and commercialization of innovation and technology. Section 3 discusses the roles of industrial engineering education for innovation and technology promotion to the market. Section 4 concludes by summing up the work.

2. Literature Review

2.1. Introduction to Industrial Engineering

The American Institute of Industrial Engineers in the early 1960s defined Industrial Engineering as a science related to design, improvement and installation of an integrated system, namely human, material, equipment and energy that refers to specific knowledge and skills in mathematical, physical and social sciences with engineering and design analysis methods to determine, predict, and evaluate the results obtained by a system.

This science emerged and became important in its existence along with the industrial revolution. The industrial revolution gave rise to a new institution that had never been known before namely the factory. It was then that industrial engineering disciplines began to emerge and develop to meet the need to design and organize factories [62]. In line with the design and organization of the factory, industrial engineering also continued to evolve to become a scientific discipline that was formally taught for the first time at Pennsylvania State University, the USA in 1906 [63]. Industrial engineering disciplines are included in engineering disciplines which are related to design (design), what is called systems,
components, and processes to meet people's needs. The uniqueness of industrial engineering disciplines compared to other engineering disciplines is that there are human elements that are not only users but also play an important role in operating a system so that the system can run at a high level of performance [62].

Research on scientific trends in industrial engineering has been carried out by previous researchers. Uys [64], argued that industrial engineering science has now undergone development. Industrial engineering science plays a role in the microscope (production floor), production management (planning, organizing, operating and controlling production systems, and environmental systems (political-socio-economic-cultural-defense-law) aspects in every step of decision making [65]. Dastkhan [66] stated that the scientific development of industrial engineering in various countries has a strong relationship with the development of the country's industry and economy. Industrial engineering science spreads in various fields such as management and engineering. Pratiwi et al [67] argued that industrial engineering is a science that has undergone development every year, and will continue to grow in the future. This science has a lot of relevance to other scientific fields, so it is very interesting to study it more deeply. In addition, Pratiwi et al [67] studied the scientific trend in industrial engineering research. The trend was traced from the body of knowledge of industrial engineering science which consists of manufacturing systems engineering, human factors engineering, management systems, and operation research. The development of those four fields was spread into 15 research fields, namely materials, operations research, ergonomics, mechanics, mechanics, product design, supply chain, industry statistics, quality, finance, logistics, information systems, inventory, environmental, and energy.

2.2. Industry 4.0 framework and contributing digital technologies

The fourth industrial revolution, commonly termed as industry 4.0, is not just about the industry. It is about overall transformation using digital integration and intelligent engineering. It is quoted as the next level of manufacturing where machines will redefine themselves in how they communicate and perform individual functions [25]. The notion of Industry 4.0 was coined by Kagermann et al. [68] which fuses the virtual and the real world with an emphasis on engineering applications such as robotics, digitization, and automatization.

Industry 4.0, involves fast and disruptive changes that embrace digital manufacturing, network communication, computer, and automation technologies, as well as many other relevant areas [69]. This new industrial paradigm embraces a set of technological developments, such as CPS, IoT, Robotics, Big Data, Cloud Manufacturing and Augmented Reality, that will influence both products and processes, allowing efficiency and productivity improvements among companies that will adopt such technologies [70]. Furthermore, Industry 4.0 will be led to deep changes in industry and manufacturing sectors, having strong impacts along the whole value chains and providing a set of new opportunities regarding business models, production technology, the creation of new jobs and work organization [71].

Industry 4.0 is driven by three factors, i.e. (1) digitization and integration of vertical and horizontal value chains, (2) Digitisation of product and service offerings, and (3) Digital business models and customer access [72]. Figure 1 shows the driver factors in industry 4.0.
Figure 1. Industry 4.0 framework
Source: PwC (2015) [72]

(1) Digitization and integration of vertical and horizontal value chains
Industry 4.0 digitizes and integrates processes vertically across the entire organization, from product development and purchasing, through manufacturing, logistics, and service. All data about operations processes, process efficiency, and quality management, as well as operations planning, are available real-time, supported by augmented reality and optimized in an integrated network. Horizontal integration stretches beyond the internal operations from suppliers to customers and all key value chain partners. It includes technologies from track and trace devices to real-time integrated planning with execution.

2) Digitization of product and service offerings
Digitization of products includes the expansion of existing products, e.g. by adding smart sensors or communication devices that can be used with data analytics tools, as well as the creation of new digitized products which focus on completely integrated solutions. By integrating new methods of data collection and analysis, companies are able to generate data on product use and refine products to meet the increasing needs of end-customers.

3) Digital business models and customer access
Leading industrial companies also expand their offering by providing disruptive digital solutions such as complete, data-driven services and integrated platform solutions. Disruptive digital business models are often focused on generating additional digital revenues and optimizing customer interaction and access. Digital products and services frequently look to serve customers with complete solutions in a distinct digital ecosystem.
2.3. Industry 4.0 characteristic
The present 4th industrial revolution, which began in the 2000s, has made automation increasingly developed primarily in the cyber-physical production system. This has broadly surpassed the development of technology known as smart factories, the internet of things, smart industry and advanced manufacturing industries [73].

The characteristics of Industry 4.0 are a combination of the latest technological developments such as physical cyber systems, information and communication technology, communication networks, big data and cloud computing, modeling, virtualization, simulations and equipment that have been developed to facilitate human-computer interaction [73].

![Figure 2. Manufacturing Strategy Option](source)

Figure 2 shows a comparison between industry 4.0 and the previous industrial revolution. Based on the figure, it is known that the concept of industry 4.0 promises many opportunities for positive change current manufacturing, including mass customization capabilities, production flexibility, increasing production speed, higher product quality, lowering failure rates, optimizing efficiency, data-based decision making, better customer approaches, new methods of value creation (value) and improve work-life [73] [75] [76] [77]. In the Industry 4.0 era, it is very important to collaborative manufacturing to get benefits not only flexibility and quality but also time to market, cost efficiency and quality.

2.4. Innovation and technology commercialization
Commercialization is a program or activity that increases value or reduces the cost of integrating new products or services [78]. This process will provide economic added value and will provide income for higher education institutions. One of the most commercialized aspects is a technology called technology commercialization. Technological innovations that are not developed economically will only stop as laboratory products or even libraries. With the process of commercializing the technology, technological innovations can be applied or consumed appropriately and will generate economic benefits for the inventor.
Osawa & Miyazaki [79] developed the process framework from research to commercialization. This is shown in Figure 3. There are 4 periods in this process, namely (1) from R & D to technology transfer, to product launch, and (2) commercialization after product launch, through to new product and success as a business. In this study, the "valley of death" was considered as the gap between product launch and when the business became success [79]. “The valley of death” usually cause various technology products that are unsuccessful to be launched in the market. It occurs in intermediate processes between technology development and technology commercialization where the funding to lift prototype into the market product is likely to be insufficient [60].

![Figure 3. Technology commercialization process](source)

Source: Osawa and Miyazaki (2006) [79]

3. Discussion

3.1. The Roles of Industrial Engineering Education

(1) Green Supply Chain Management
Integrating environmental thinking into supply chain management, including product design, material sourcing, and selection, manufacturing process, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life [80].

(2) The full vertical and horizontal operational value chains in digitals era
the outcome of Industry 4.0 projects, companies will need to work hard to overcome initial challenges. It can be difficult to secure funding and stakeholder buy-in, as the economic benefits case of digitization is not always easy to calculate. And initially, teams will only be able to provide very limited proof of concept and demonstration of technologies. Figure 4 shows industry 4.0 pilot opportunities exist along the full vertical and horizontal operational value chains that can help address these issues. Not every project will succeed, but they will all help to learn the approach that works for the company. With evidence from early successes, buy-in from the organization can be gained, and funding for a larger rollout can be secured.
Figure 4. Full vertical and horizontal operational value chains in digital era
Source: PwC (2015) [72]

(3) Develop a bridging system between innovations and technology commercialization

Figure 5. Shows the Technopreneurship as a Bridging System. A Technopreneurship course in university is expected to be a bridging system for academician in the technology commercialization process. As for the bridging system of technology commercialization in university, the course not only provides handbook but also other facilities regarding Technopreneurship activity. Normally, the lecturer will invite students to join external learning facilities such as public lecture, workshop or seminar. Students can share the experience and knowledge with expert, professional and practitioners. In another occasion, they probably can find a business opportunity or even join as a tenant. As the great number of facilities provided in both internal and external courses, students have a big chance to be a successful technopreneur. Besides they get an insight of being a successful businessman, they will be directed into a desirable business. Another facility that student might get from the course is a Technopreneurship-based thesis.

Figure 5. Technopreneurship as a Bridging System
(4) Support an Incubation Process
The urgency of the incubation process in a university has attracted some researchers’ interest to conduct related-study while universities are continuously developing their system in the incubation process. Gübeli and Doloreux [81] and Albadvi and Saremi [82] are the examples. They examine the business process of university incubator in Linköping University and university in Iran respectively. In general, Yuniaristanto et. al. [83] illustrates the incubation process in university as two main sequential processes: technology incubation and Technopreneurship. Technology incubation process will lead the technology product to be certified and licensed. Meanwhile, Technopreneurship process develops a business plan proposal into a new firm with mass production and developing investment.

Universitas Sebelas Maret (UNS) as one of the university, which tends to participate in knowledge-based economy shifting has its own scheme in the incubation process. Start from RnD activities, UNS provides a facility such as a grant and scientific consultancy nevertheless subject to availability. Through the Technology Readiness Level (TRL) assessment scheme, the RnD product will be selected for a shortlisted product to be incubated. On the other hand, ‘CEO hunting’ scheme in university is in searching of tenants for respective technology. Along with those processes, every technology developed in university is encouraged to be licensed or certified and can be assisted by IPR Management Unit in UNS. Qualified technology, tenant either with certified IP as supplementary or not will continue to co-incubation process held by incubation center in UNS called Pusat Inovasi Teknologi (PIT). Final expected output from the process is an establishment of technology-based start-up (PPBT) [84].

Technology commercialization as an implementation of knowledge-based business era is need to be supported by university as its shifting of role particularly in economy development. Through incubation process in Incubator Centre, university will be able to establish a PPBT managed by CEO from their academician.

![Figure 6. Incubation Process System Framework in UNS](image)

Wicaksana [85] in his study elaborates the system framework used in the incubation process of PIT in more detail as seen in figure 6. According to his output, there are three main stages in the process: pre-incubation, incubation, and post-incubation. The pre-incubation stage starts from data listing of prospective tenants with their technology as well as business proposal and finishes with a selection of tenant. Incubation stage mainly consists of training and mentoring activities for the tenant. Technology product is expected to be certified, licensed and ready to be launched while the business proposal is
expected to transform into the ventured start-up. In this stage, PIT plays an important role to provide funding, mentor and other facilities as the tenants show progress. However, this stage is also critical for PIT to decide continuation of the tenant in the co-incubation process prior to their progress through routine monitoring and evaluation. The last stage of the process encourages the tenant to develop their business, build partnership and perform business acceleration. Exit strategy of the tenant is decided in this stage as the final step of the whole process.

3.2. Promoting Innovation and Technology Commercialization

(1) Promote a capable human resource through Technopreneurship
An academician with their invention or the business idea of another academician invention can learn about the way to make their product become profitable through the course and present it afterward. By optimizing facility offered by the course, they also may get support or venture from external organization or institution. Once they are rewarded and show excellent progress of incubation, their start-up may be established soon. Hence, they have done duty as the role of the university is recently shifting to promote technology-based economy [86][87][88].

Creative ideas of academician in the university are expected not to be stopped as mere reference stack in a library by the presence of Technopreneurship course. Instead, to be ignored, research invention and potential business idea are gathered in PIT UNS to get further development. In other words, inventor and technology-based businessman candidate are met by the course. Eventually, both of them will gain profit from their creative ideas. This effect is illustrated in figure 7.

(2) A systematic Technopreneurship course
UNS has conducted entrepreneurship course as a compulsory for students in 2 credits and is enrolled normally in the final semester. The course aims to give an insight and basic knowledge about business, especially for non-business students. However, some of them successfully create a business proposal and transform it into a small start-up while the other has a thesis with a related theme.

Technopreneurship course as an elective course with 2 credits acts as a further course in entrepreneurship specifically for the technology-based product. Students will be introduced to technology commercialization and incubation concept. They are also given chances in more workshop or seminar and will be invited to join tenant selection in PIT. Qualified tenant will be incubated for 2 to 3 years [85]. The role of Technopreneurship course in UNS can be seen in figure 8.
There is four urgency of Technopreneurship course for university [61]. First of all, Technopreneurship course promotes utilization of technology from the university in entrepreneurship/business area. Hence, research output will be more economically beneficial and useful for the public. In other words, this course will transfer innovative product into various type of business entity. The distinct process of Technopreneurship compared to entrepreneurship encourage academician to enhance their skill in business, management as well as product development. Thus, the university is able to create highly qualified and competitive human resources. Eventually, the presence of a start-up as the desired result of the course provides more vacancies and reduces unemployment.

(3) Competitiveness improvement of innovation and technology

The level of competition of innovation and technology product can be analyzed using Porter’s Five Forces framework. It is especially useful when starting a new business or when entering a new industry sector. According to this framework, competitiveness does not only come from competitors. Rather, the state of competition in an industry depends on five basic forces: a threat of new entrants, bargaining power of suppliers, bargaining power of buyers, threat of substitute products or services, and existing industry rivalry. The collective strength of these forces determines the profit potential of the industry and thus its attractiveness. If the five forces are intense, almost no company in the industry earns attractive returns on investments. If the forces are mild, however, there is room for higher returns [89].

In addition, Porter’s value chain model can also be used to analyze competitiveness and to identify areas where information systems will improve business processes. The value chain model highlights specific activities in the business where competitive strategies can best be applied and where information systems are most likely to have a strategic impact. The value chain model views the university as a series or chain of basic activities that add a margin of value to a university's innovation product. These activities can be categorized as either primary activities or support activities. Primary activities are most directly related to the production and distribution of the university's products and services, which create value for the customer. Primary activities include inbound logistics, operations, outbound logistics, sales and marketing, and service. Support activities make the delivery of the primary activities possible and consist of organization infrastructure (administration and management), human resources (employee recruiting, hiring, and training), technology (improving products and the production process), and procurement (purchasing input).
We can also benchmark our business processes against competitors or others in related industries, and identify and implement industry best practices. Benchmarking involves comparing the efficiency and effectiveness of the business processes against strict standards and then measuring performance against those standards.

Industry best practices are usually identified by consulting companies, research organizations, government agencies, and industry associations as the most successful solutions or problem-solving methods for consistently and effectively achieving a business objective.

The university’s value chain is linked to the value chains of its suppliers, distributors, and customers. Figure 10 provides examples of systems for both primary and support activities of a university as a firm and of its value partners that can add a margin of value to a firm’s products or services.

Information systems can be used to achieve a strategic advantage at the industry level by working with other firms to develop industry-wide standards for exchanging information or business transactions electronically, which force all market participants to subscribe to similar standards. Such efforts increase efficiency, making product substitution less likely and perhaps raising entry costs.

**Figure 9. Porter Five Forces Model**

Source: https://www.business-to-you.com/porters-five-forces/ [89]
4. Conclusion

The Industrial Engineering Education in Industrial Engineering Department is able to survive with the implications of Industry 4.0 for Industrial Engineers in the Digital Era. The Industrial Engineering Education curriculum includes materials for human-digital skills for Industrial Engineers. The Industrial Engineering Education has many roles to support commercialization of Technology in the Digital Era, including designing a system-operational value chains, support an incubation process, promote a capable human resource – Technopreneurship & competitiveness' improvement.

Technopreneurship course is one of an example of a solution to accelerate the innovation and technology commercialization process in higher education. More measures can be exploited more in further studies in order to support Technopreneurship activity. Investigation of action that can be done by other parties in the technology commercialization scheme is another alternative future research.

5. References

[1] Industrial & System Engineering (http://www.iise.org/)
[2] Bilge P, Seliger G, Badurdeen F, Jawahir IS 2016 A Novel Framework for Achieving Sustainable Value Creation through Industrial Engineering Principles Procedia CIRP 40 516 – 523
[3] Tunzelmann N 2003 Historical coevolution of governance and technology in the industrial revolutions Structural Change and Economic Dynamics 14 365-384
[4] Spear B 2014 Coal – Parent of the Industrial Revolution in Great Britain: The early patent history World Patent Information 39 85-88
[5] Bottomley S 2014 Patenting in England, Scotland, and Ireland during the Industrial Revolution, 1700–1852 Explorations in Economic History 54 48-63
[6] Fischer-Kowalski M, Rovenskaya E, Krausmann F, Pallua I, Mc Neill JR 2019 Energy transitions and social revolutions Technological Forecasting and Social Change 138 69-77
[7] Liao Y, Ramos L F P, Saturno M, Deschamps F, Loures E F R, Szejka A L 2017 The Role of Interoperability in The Fourth Industrial Revolution Era IFAC-PapersOnLine 50 12434-12439
[8] Syam N, Sharma A 2018 Waiting for a sales renaissance in the fourth industrial revolution: Machine learning and artificial intelligence in sales research and practice Industrial Marketing Management 69 135-146
[9] Pearson P J G, Foxon T J 2012 A low carbon industrial revolution? Insights and challenges from past technological and economic transformations Energy Policy 50 117-127

[10] Sakr D 2017 Sustainability and Innovation: The Next Global Industrial Revolution Journal of Cleaner Production 142 3355-3356

[11] Kim J 2018 Are countries ready for the new meso revolution? Testing the waters for new industrial change in Korea Technological Forecasting and Social Change 132 34-39

[12] Kim J, Torneo A 2018 Proliferation of meso-industrial revolutions: is industry 4.0 just one of the waves? Technological Forecasting and Social Change 132 1

[13] Hoernicke M, Horch A, Bauer M 2017 Industry contribution to control engineering education: An experience of teaching of undergraduate and postgraduate courses IFAC-PapersOnLine 50 133-138

[14] Abdullah S R S, Takriff M S, Mohamad A B, Kofilia N T, Rahaiza N A, Badar M S N 2012 Programme Outcome Achievements of Chemical and Biochemical Engineering Graduates Through Exit Survey Procedia - Social and Behavioral Sciences 60 294-299

[15] Sengupta D, Huang Y, Davidson C I, Edgar T F, Edene M R, El-Halwagi M M 2018 Sustainable Manufacturing Education Modules for Senior Undergraduate or Graduate Engineering Curriculum Computer Aided Chemical Engineering 44 1657-1662

[16] Chikuku T, Chingwusa S, Mushiri T 2017 Industrial Secondment as a Tool to Enrich Engineering Education in Southern Africa Procedia Manufacturing 7 15-21

[17] Braghiorelli L F, Ribeiro J L D, Weise A D, Pizzolato M 2016 Benefits of educational games as an introductory activity in industrial engineering education Computers in Human Behavior 58 315-324

[18] Bures M 2015 Efficient Education of Ergonomics in Industrial Engineering Study Program Procedia - Social and Behavioral Sciences 174 3204-3209

[19] Palma M, Ríos I, Guerrero D 2012 Higher Education in Industrial Engineering in Peru: Towards a New Model Based on Skills Procedia - Social and Behavioral Sciences 46 1570-1580

[20] Sönmez M 2014 The Role of Technology Faculties in Engineering Education Procedia - Social and Behavioral Sciences 141 35-44

[21] Moreno A M, Sanchez-Segura M, Medina-Dominguez F, Carvajal L 2012 Balancing software engineering education and industrial needs Journal of Systems and Software 85 1607-1620

[22] Ayob A, Osman S A, Omar M Z, Jamaluddin N, Kofli N T, Johar S 2013 Industrial Training as Gateway to Engineering Career: Experience Sharing Procedia - Social and Behavioral Sciences 102 48-54

[23] Miller A, Bures M 2015 New approach to industrial engineering education with the help of interactive tools Procedia - Social and Behavioral Sciences 174 3413 – 3419

[24] Kádárová J, Kováč J, Durkačová M, Kádár G 2014 Education in Industrial Engineering in Slovakia Procedia - Social and Behavioral Sciences 143 157 – 162

[25] Muhuri P K, Shukla A K, Abraham A 2019 Industry 4.0: A bibliometric analysis and detailed overview Engineering Applications of Artificial Intelligence 78 218-235

[26] Dalenogare L S, Benitez G B, Ayala N F, Frank A G 2018 The expected contribution of Industry 4.0 technologies for industrial performance International Journal of Production Economics 204 383-394

[27] Yli-Ojanaerä M, Sierla S, Papakonstantinou N, Vyatkin V 2018 Adapting an agile manufacturing concept to the reference architecture model industry 4.0: A survey and case study Journal of Industrial Information Integration, In press, corrected proof, Available online 25 December 2018

[28] Sackey S M & Bester A 2016 Industrial engineering curriculum in industry 4.0 in a south african context South African Journal of Industrial Engineering 27 101-114

[29] Roblek V, Meško M, Krapež. A 2016 A complex view of industry 4.0 SAGE Open 6 1-12

[30] Paritala P K, Manchikutla S, Yarlagadda P K D V 2017 Digital Manufacturing- Applications Past, Current, and Future Trends Procedia Engineering 174 982-991

[31] Chen D, Heyer S, Ibbotson S, Salonitis K, Steingrímsson J G, Sebastian 2015 Direct digital manufacturing: definition, evolution, and sustainability implications Thiede Journal of Cleaner Production 107 615-625
[32] Sato R S, Borsato M, Iaksch J S, Fernandes E C, Oliveira K V 2018 Product Development, Digital Manufacturing, and Product Manufacture Information: A Bibliometric and Systemic Analysis Proc. of the 2018 Annual Conference of the Procedia Manufacturing 17 190-197

[33] Lasi H, Fette P, Kemper H G, Hoffmann T M F 2014 Industry 4.0 Bus. Inf. Syst. Eng. 6 239-242

[34] Trappey A J C, Trappey C V, Govindarajan U H, Sun J J, Chuang A C 2016 A review of technology standards and patent portfolios for enabling cyber-physical systems in advanced manufacturing Adv. Eng. Inf., 4

[35] Apreda R, Bonaccorsi A, 'Orletta F D, Fantoni G 2016 Functional technology foresight. A novel methodology to identify emerging technologies Eur. J. Futur. Res. 4 13

[36] Hecklau F, Galeitzeck M, Flachs S, Kohl H 2016 Holistic Approach for Human Resource Management in Industry 4.0 Procedia CIRP 54 1-6

[37] Wittenberg C 2016 Human-CPS Interaction - requirements and human-machine interaction methods for the Industry 4.0 IFAC-PapersOnLine 49 420-425

[38] Longo F, Nicoletti L, Padovano A 2017 Smart operators in industry 4.0: A human-centered approach to enhance operators’ capabilities and competencies within the new smart factory context Computers & Industrial Engineering 113 144-159

[39] Liu W, Zhan J, Wang C, Li S, Zhang F 2018 Environmentally sensitive productivity growth of industrial sectors in the Pearl River Delta Resources Conservation and Recycling 139 50-63

[40] Rahman M M, Kashem M A 2017 Carbon emissions, energy consumption and industrial growth in Bangladesh: Empirical evidence from ARDL cointegration and Granger causality analysis. Energy Policy 110 600-608

[41] Lin J Y, Sun X, Wu H X 2015 Banking structure and industrial growth: Evidence from China, Journal of Banking & Finance 58 131-143

[42] Giuri P, Munari F, Scandura A, Toschi L  The strategic orientation of universities in knowledge transfer activities. Technological Forecasting & Social Change, 1-18

[43] Sengupta A, Ray A S 2017 University research and knowledge transfer: A dynamic view of ambidexterity in british universities Research Policy 46 881-897

[44] Anatan L 2015 Conceptual Issues in University to Industry Knowledge Transfer Studies: A Literature Review Procedia - Social and Behavioral Sciences 211 711-717

[45] Xu J, Hou Q, Niu C, Wang Y, Xie Y 2018 Process optimization of the University-Industry-Research collaborative innovation from the perspective of knowledge management Cognitive Systems Research 52 995-1003

[46] Shim S O, Park K B, Choi S Y 2018 Sustainable Production Scheduling in Open Innovation Perspective under the Fourth Industrial Revolution. J. Open Innov. Technol. Mark. Complex. 4 42

[47] Schiuma G, Carlucci D 2018 Managing Strategic Partnerships with Universities in Innovation Ecosystems: A Research Agenda J. Open Innov. Technol. Mark. Complex. 4 25

[48] Tani M, Papalucu O, Sass P 2018 The System Thinking Perspective in the Open-Innovation Research: A Systematic Review. J. Open Innov. Technol. Mark. Complex. 4 38

[49] Sutopo W, Nizam M, Purwanto A, Atikah N, Putri A S 2016 A Cost Estimation Application for Determining Feasibility Assessment of Li-Ion Battery in Mini Plant Scale International Journal on Electrical Engineering and Informatics 8 189-199

[50] Sutopo W, Kadir E A 2017 An Indonesian Standard of Lithium-ion Battery Cell Ferro Phosphate for Electric Vehicle Application. TELKOMNIKA 15 584-589

[51] Sutopo W, Kadir E A 2018 Designing Framework for Standardization Case Study: Lithium-Ion Battery Module in Electric Vehicle Application, International Journal of Electrical and Computer Engineering 8 220–226

[52] Sutopo W, Fauzan M I R, Yuniaristanto 2016 A Comparative Analysis of Natural Fiber Reinforced for an Interior Electric Car Jurnal Mekanikal 39 47-55

[53] Sutopo W, Erliza A, Ardiansyah R, Yuniaristanto, Nizam M 2016 Parametric Cost Estimation for Controlling the Development of Electric Vehicle Prototype Jurnal Mekanikal 39 56-68
[54] Kadir E A, Shamsuddin S M, Supriyanto E, Sutopo W, Rosa S L 2015 Food Traceability in Supply Chain Based on EPCIS Standard and RFID Technology TELKOMNIKA Indonesian Journal of Electrical Engineering 13 187-194

[55] Nugraheni D D, Sutopo W, Hisjam M, Priyandari Y 2016 Preliminary study of Benefits and Barriers-Costs RFID Technology Implementation on Traceability System of Banana in Indonesia. Jurnal Mekanikal 39 1-10

[56] Belitski M, Aginskaja A, Marozau R 2018 Commercializing university research in transition economies: Technology transfer offices or direct industrial funding? Research Policy, In press, corrected proof, Available online 16 October 2018

[57] Hsu D W L, Shen Y, Yuan B J C, Chou C J 2015 Toward successful commercialization of university technology: Performance drivers of university technology transfer in Taiwan Technological Forecasting and Social Change 92 25-39

[58] Siegel D S , Waldman D, Link A 2003 Assessing the impact of organizational practices on the relative productivity of university technology transfer offices: an exploratory study Research Policy 32 27-48.

[59] Wicaksana D E P, Yunaristanto and Sutopo W 2015 Identification of Incubation Scheme By Incubator In University Innovation Center to Develop Indonesian Economy Proceedings of the Joint International Conference on Electric Vehicular Technology and Industrial, Mechanical, Electrical and Chemical Engineering (ICEVT & IMECE) Surakarta

[60] Kusuma C, Sutopo W, Yunaristanto, Hadiyono S and Nizam M 2015 Incubation Scheme of the University Spin Off to Commercialize the Invention in Sebelas Maret University The International MultiConference of Engineer And Computer Scientist Hong Kong

[61] Sutopo W 2015 Book Review: Technopreneurship, Surakarta, Central Java

[62] Samadhi, T M A Ari 2012 Pendidikan dan Keilmuan Teknik Industri Masa Depan di Indonesia (Trans: Future Industrial Engineering Education and Science in Indonesia) Seminar Nasional Pendidikan Teknik Industri Konvensi Nasional I, BKTI-PII.

[63] Zandin K B 2001 Maynard's Industrial Engineering Handbook 5th ed. (New York: McGraw Hill)

[64] Uys J W, Schutte C S L, Van Zyl W D 2011 Trends in an International Industrial Engineering Research Journal: A Textual Information Analysis Perspective Proceedings of the 41st International Conference on Computers & Industrial Engineering.

[65] Wignjosoebroto A 2001 Peran Strategis Teknik Industri bagi Dunia Industri di Indonesia dalam Menghadapi Persaingan di Era Pasar Bebas (Trans: Strategic Role of Industrial Engineering for the Industrial World in Indonesia in Facing Competition in the Free Market Era)

[66] Dastkhan H and Owlia M S 2009 Study of Trends and Perspectives of Industrial Engineering Research South African Journal of Industrial Engineering 20 1-12

[67] Pratiwi A, Mahardika F A, Sutopo W 2016 Tren Keilmuan Teknik Industri Oleh Praktisi Teknik Industri Dunia (Trans: Trends in Scientific Industrial Engineering by Industrial Engineering Practitioners) Proceeding of The 3rd Industrial Engineering Conference Surakarta

[68] Kagermann H, Lukas W D, Wohlster W 2011 Industrie 4.0: Mit dem internet der dinge auf dem weg zur 4. industriellen revolution (Trans: Industry 4.0: With the Internet of Things on the way to the 4th industrial revolution) VDI Nachr. 13 11

[69] Zhou K, Liu T, and Zhou L 2016 Industry 4.0: Towards Future Industrial Opportunities and Challenges International Conference on Fuzzy Systems and Knowledge Discovery 2147–2152.

[70] Schmidt R, Möhring M, Härtling R C, Reichstein C, Neumaier P, and Jozinović P 2015 Industry 4.0 - Potentials for Creating Smart Products: Empirical Research Results International Conference on Business Information Systems 16–27.

[71] Pereira A C, Romero F 2017 A review of the meanings and the implications of the industry 4.0 concept Procedia Manufacturing 13 1206–1214

[72] PwC 2015 Industry 4.0: Building the digital enterprise [online]. Available: http://www.pwc.com/industry40

[73] Kinzel H 2016 Industry 4.0 – Where Does This Leave The Human Factor? [Online] Available: https://www.researchgate.net/publication/308614137_Industry_40_-_Where_does_this_leave_the_human_factor.
[74] Irianto D 2018 Implementation of Industry 4.0 for “Conventional Industry” KONVENSI NASIONAL BIKTI 2018
[75] Kagermann H 2013 Securing the Future of German Manufacturing Industry, Final Report of The Industrie 4.0 Working Group, Acatech.
[76] Schlaepfer R A 2014 Industry 4.0: Challenges and Solutions for the Digital Transformation and Use of Exponential Technologies [online] Available: http://www.industrie2025.ch/fileadmin/user_upload/ch-en-delloitindustry-4-0-24102014.pdf.
[77] Wahlster W 2012 Industry 4.0: From Smart Factories to Smart Products.
[78] Diharjo K, Sutopo W, Sambowo K A, Purwanto, Musyawaroh, Paryanto, Yuniaristanto, Karyanda R, Suryanto H and Sudarisman N 2014 Kewirausahaan Berbasis Teknologi (Technopreneurship) (Trans: Technology-based Enterpreneur) (Surakarta: UNS Press)
[79] Osawa Y & Miyazaki K 2006 An empirical analysis of the valley of death: Large-scale R&D project performance in a Japanese diversified company Asian Journal of Technology Innovation 14 93-116
[80] Srivastava S K 2007 Green supply-chain management: A state-of-the-art literature review International Journal of Management Reviews 9 53–80.
[81] Gübeli M H and Doloreux D 2005 An Empirical Study of University Spin-Off Development European Journal of Innovation Management 8 269-282
[82] Albadvi A and Saremi H Q 2006 Business Incubation Process Framework: The Case of Iranian High-Tech Innovations IEEE International Conference on Management of Innovation and Technology.
[83] Yuniaristanto, Wicaksana D E P, Sutopo W and Nizam M 2014 Proposed Business Process Technology Commercialization: A Case Study of Electric Car Technology Incubation International Conference on Electrical Engineering and Computer Science Bali
[84] Pusat Inovasi Teknologi UNS 2015 Business Plan 2015 of PIT UNS (Surakarta: Pusat Inovasi Teknologi UNS)
[85] Wicaksana D E P 2016 System Framework of University Technology Based Start-Up Development: Case Study: PIT UNS (Surakarta: digilib.uns.ac.id)
[86] Bramwell A and Wolfe D A 2008 Universities and Regional Economic Development The Entrepreneurial University of Waterloo Research Policy 371135-1187
[87] Leung M and Mathews J A 2015 IDEAS Home [Online] Available: https://ideas.repec.org/a/ids/iijtisy/v1y2011i2p175-201.html
[88] Sutopo W, Astuti R W, Yuniaristanto, Purwanto A, Nizam M 2015 Model To Measure University’s Readiness For Establishing Spin-Offs: Comparison Study IAENG Transactions on Engineering Sciences 173-186
[89] https://www.business-to-you.com/porters-five-forces/
[90] https://paginas.fe.up.pt/~als/mis10e/ch3/chpt3-3bullettext.htm