The Evolution of Scientific Management: From Industrial Engineering to Industrial Data Science

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1. Introduction

Ever since the First Industrial Revolution, optimization measures and operational decisions in the manufacturing industry rely on quantitative and fact-based assessments. New advancements during the on-going digitalization and globalization of nowadays world of work represent a logical and inevitable continuation of the observable trends in science and technology. Against the background of this natural development, emerging potentials through *Data Science* do not necessarily represent a paradigm shift, but rather a continuation of the development of *Industrial Engineering* (IE). In view of the currently inflated expectations with regard to Data Science's problem-solving capacities and its promises of economic rationalization, this paper draws references to major representatives and pioneers of IE, such as *Frank* and *Lillian Gilbreth*, *John Burbidge*, *William E. Deming* and *Eliyahu M. Goldratt*. Using their respective field as examples, we summarize the development of IE to date. Based on current trends, this paper looks at scientific trends to outline a scope for the future evolution of Industrial Data Science.

2. Fundamentals

The roots of IE stem from FREDERICK W. TAYLOR, whose work *Principles of Scientific Management* was instrumental in shaping the course of industrial manufacturing [1]. Along a belief in *one best way*, Scientific Management encourages fact-based decision-making based on measurable data. Thus, quantifiably optimal solutions take the place of practices previously determined by rule-of-thumb methods [2]. The onset of a world-wide adoption of Scientific Management Principles defines the starting point for the continuous evolution of TAYLOR's vision. It led to the emergence of IE, as it is known in manufacturing today. IE includes all tasks concerned with 'the design, improvement and installation of integrated systems of people, materials, information, equipment and energy. It draws upon specialized knowledge and skills 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 systems', as defined by the *Institute of Industrial and Systems Engineers* [3]. As such, Industrial Engineers lead continuous improvement processes and provide system-, method- and problem-solving competences, along the ever-evolving requirements of various other skills [4]. In this paper, we outline the utilization of Industrial Data Science (IDS) as the latest of such competences based on a case study of IE pioneers.

3. Pioneer Case Studies

This paper reviews the origins of IE with reference to four historical pioneers, draws a connection to current day usage, and considers possibilities for future applications and research of IDS. We outline past, present and future work of the following pioneers:

- FRANK and LILLIAN GILBRETH, whom we consider pioneers of *Time and Motion Study*, lay the foundation for the first predetermined motion time system that is nowadays widely used, e.g. in Motion Time Analysis (MTM) [5]. Usage of Machine Learning allows leveraging further potentials, such as automatic analysis of recorded motions or intelligent suggestions for process improvement [6].
- JOHN BURBIDGE's work on *Group Technology* lead to the first industrial system for grouping objects and resources according to their inherent similarity [7]. The classification system to structure work pieces according to function, shape and technological features is at the heart of contemporary planning approaches as well as of future IDS applications, such as Process Mining for value stream mapping.
- Given his influential work in the field of Quality Management, we consider WILLIAM E. DEMING to be another pioneer of IE [8]. His work led to Quality Control Charts and Statistic Process Control, which laid the foundation for modern quality management. This gave rise to the potential for using supervised and unsupervised Machine Learning models for enhanced quality-based process control.
- As founder of the Theory of Constraints, ELIYAHU M. GOLDRATT is an IE pioneer in the field of *Process Control* [9]. This led to a shifting focus of optimization efforts to bottleneck stations and the development of bottleneck-oriented process control systems. In the future, data-driven predictions of emerging bottleneck stations can help to mitigate output- or capacity-losses or to counteract shifting behavior.

Summarizing past, present and future trends, IE and IDS involve similar tasks for fact-based decision-making processes: Often, the first step is to *access* the necessary data sources. The second step is to *analyze* the provided data, where a method suitable for the analysis task must be selected from the pool of available options. The third step is to *apply* the results of the analysis to the industrial use case, creating economic value. Finally, to *administrate* these tasks a wealth of supporting duties needs to be fulfilled.

4. Conclusion

The four case studies of the pioneers of IE in this paper show the development of Scientific Management in different domains as an evolutionary process. We consider the trend towards a widespread application of Industrial Data Science as the inevitable result of a decades-spanning development process. Leveraging the growing data sources is just the next logical step in an environment that relies on fact-based and quantified decision-making. Thus, the application of Data Science in Industrial Engineering under the umbrella of Industrial Data Science will continue to grow in importance in the coming decades. At their core, manufacturing companies will continue to use the original concepts of the discussed pioneers, but increase the effectiveness through the addition of digital and data-driven methods and tools. Accessing, analyzing, applying and administrating data is going to be vital for future applications of Industrial Data Science. For future competitiveness, an Industrial Engineer's collection of applicable methods and tools has to be expanded to accommodate for the capabilities of IDS. The multitude of requirements for an integrated and networked application of industrial data analysis in dynamic value creation networks will shape the further course of IDS research.

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References

1. F. W. Taylor, *The Principles of Scientific Management*. New York, London: Harper & Brothers Publishers, 1911.
2. J. A. Merkle, *Management and Ideology: The Legacy of the International Scientific Management Movement*. Berkeley and Los Angeles: UC Press, 1980.
3. IISE, *What is industrial and systems engineering? (IISE official definition)*. [Online]. Available: https://iise.org/details.aspx?id=282 (accessed: April, 1, 2021).
4. Richter and J. Deuse, "Industrial Engineering in Modern Production (in German)," *Zeitschrift f. angew. Arbeitswissenschaft*, vol. 207, no. 1, pp. 6–13, 2011.
5. MTM ASSOCIATION e. V., *Brand History*. [Online]. Available: https://mtm.org/en/brands/brand-history (accessed: April, 1, 2021).
6. J. Deuse, L. Stankiewicz, R. Zwinkau, and F. Weichert, "Automatic Generation of Methods-Time Measurement Analyses for Assembly Tasks from Motion Capture Data Using Convolutional Neuronal Networks," *International Conference on Applied Human Factors and Ergonomics*, pp. 141–150, 2019.
7. J. L. Burbidge, *The Introduction of Group Technology*. London: W. H., 1975.
8. W. E. Deming, *Elementary Principles of the Statistical Control of Quality: A Series of Lectures*. Tokyo: Nippon Kagaku Gijutsu Remmei, 1950.
9. E. M. Goldratt and J. Cox, *The Goal*. NY: North River Press, 1984.