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Industrial Engineering of Systems - System Industrial Engineering

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Abstract

"Industrial Engineering is Human Effort Engineering and System Efficiency Engineering. It is an engineering discipline that deals with the design of human effort and system efficiency in all occupations: agricultural, manufacturing and service. The objectives of Industrial Engineering are optimization of productivity of work-systems and occupational comfort, health, safety and income of persons involved." This definition of Industrial Engineering was proposed by Narayana Rao. In systems engineering terminology, "functional design discipline" and "specialty engineering discipline" are recognized. Industrial Engineering is a specialty engineering discipline dealing with human effort in systems and related issues and system efficiency. Hence industrial engineering of systems or system industrial engineering is appropriate terminology to indicate that there is scope to industrial engineer a system and improve it.

The paper highlights some of the areas wherein system performance will be improved by industrial engineering of the system and explains the activities in industrial engineering of systems. The paper advocates that systems engineering literature has to recognize relevance of industrial engineering department in the system design process and discusses the potential of various IE tools in improving system efficiency. Systems Engineering needs to identify IE as one of the specialty engineering disciplines in the systems design process.

Introduction

Institute of Industrial Engineers (IIE), the professional institute representing industrial engineering globally with the punch line "Global Association of Productivity and Efficiency Professionals" describes industrial engineering (IE) as a discipline concerned with design of systems. The definition provided is, "Industrial engineering is concerned with the design, improvement and installation of integrated systems of people, materials, 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 systems."(IIE,2010).

It is important to notice that the profession does not define its scope as design of system, but says that it is concerned with design of systems or it is related to the design of system. It can also be said that industrial engineering has a role to play in the design of systems. Industrial engineering can be visualized as a collection of techniques or methodologies and the application of those techniques in system design process can be viewed as industrial

engineering of systems. Systems engineering methodology provides opportunity for systems analysis and optimization activity in number of performance areas during the system design process. Industrial engineering definition clearly identifies that industrial engineering is involved in the analysis of systems to predict and evaluate the results in the dimensions which are its focus areas. Hence industrial engineering of systems is an appropriate term to use to describe the role of industrial engineering in systems design activity or system engineering process.

The purpose of the paper is to point out that Industrial Engineering has techniques that contribute to improve the performance of the systems in certain dimensions and these techniques can be applied in the systems design process. Systems engineering process identifies the stages of system synthesis and system analysis & optimization. Industrial engineering is to be applied during system analysis and optimization activity. In the paper, the roles of some of the important techniques of industrial engineering in system design are brought out to advocate the use of terms "industrial engineering of systems" and "system industrial engineering." Such a usage, in practice will lead to industrial engineering becoming an important activity in systems design process and systems will become more efficient at the design stage itself and productive as IE techniques are applied during the system design process.

Industrial Engineering Techniques

The main areas of industrial engineering can be identified as human effort engineering and system efficiency engineering (Narayana Rao, 2006). Human effort engineering is designing and redesigning human effort in work place to promote productivity, comfort, safety and health of workmen. System efficiency engineering improves the efficiency with which resources are used in design, production and distribution processes. The resources specifically identified in the industrial engineering definition are people, materials, information, equipment and energy. Apart from these two core activities, certain other activities are also performed by the industrial engineering function temporarily or for longer durations in various organizations.

Under the Human Effort Engineering category the following techniques or group of techniques can be listed.

1. Principles of Motion Economy and Motion Study.
2. Work Measurement
3. Ergonomics
4. Safe Work Practice Design
5. Wage Incentives and Job Evaluation

Under the System Efficiency Engineering component, the following techniques or group of techniques can be categorized.

1. Method Study and Methods Design
2. Value Engineering
3. Statistics Based Techniques: Statistical Quality Control (SQC), Statistical Process Control (SPC), and Six Sigma Projects etc.
4. Operations Research and Quantitative Techniques
5. Plant Layout Studies for reduction of material movement, operator movement and movement of salesmen etc.
6. Engineering Economics
7. IE Solutions in Specific Functions: Single Minute of Exchange of Dies (SMED), Lean Production Systems, Business Process Reengineering and Gantt Charts etc.

All the techniques categorized under Human Effort Engineering or System Efficiency Engineering contribute to the proper functioning of work systems or business systems and they can be applied and

need to be applied in the design stage of systems. Application of these techniques during the system design stage can be termed as industrial engineering of systems. Systems engineering process provides scope for use of variety of techniques in the development of systems and industrial engineering of systems also needs to be identified as one of the important steps in systems design methodology.

Systems Engineering

The International Council on Systems Engineering (INCOSE) is working in the area of systems engineering to develop and disseminate the interdisciplinary principles and practices that enable the realization of successful systems.

INCOSE defines systems engineering as an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem (INCOSE, 2010).

Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs. Industrial engineering needs to be categorized as a specialty group that participates in the system design process.

Design synthesis and system validation are highlighted as two important steps in the INCOSE explanation. In the systems engineering process outlined by him, (Martin, 1997) used the terms, system synthesis and system analysis & optimization. System synthesis is explained as developing the architecture that meets the functional and performance requirements. The system has to be functional to deliver an output and then the output has to be acceptable to the customer. The performance requirements will be met when the customer accepts the output. The design or the architecture proposed in the synthesis phase is subjected to system analysis and optimization. Martin mentions production engineering analysis, test and verification analysis, deployment & Installation analysis, operational analysis, supportability analysis, training analysis, disposal analysis, environmental analysis, and life cycle cost analysis as analyses carried out during system analysis and optimization phase. In this paper, we advocate that industrial engineering analysis also needs to be carried out during this analysis phase and improvements are to be carried out to the system.

Industrial and Systems Engineering

Some scholars in the field of industrial engineering are proposing the name of industrial and systems engineering as more appropriate description of the industrial engineering activity. Adedeji Badiru (Badiru, 2006) edited a handbook with the title 'Handbook of Industrial Systems Engineering." (Oke, 2006) in writing a chapter with the title "An Overview of Industrial and Systems Engineering" expressed the opinion that there is a great need for a published work that presents a holistic overview of industrial and systems engineering. He has stated that his chapter is developed in a creative and innovative way and bridges the important gaps in current approaches to industrial and systems engineering. Oke identified the following areas as falling into industrial and systems engineering.

1. Human Factors Engineering (Ergonomics)

2. Operations Research
3. Artificial Intelligence
4. Mathematical Modeling
5. Manufacturing Systems
6. Engineering Statistics
7. Engineering Computing

In this paper, the aim is to present a case for industrial engineering of systems as one of the activities in systems design process and also to present a picture that industrial engineering discipline has sufficient content to exist as an independent discipline and it need not be associated with additional disciplines. Such association may only dissipate its focus in the process.

Industrial Engineering Techniques and Their Role in Systems Improvement

Human Effort Engineering and System Efficiency Engineering form the two core and primary focus areas of industrial engineering. Frederick Winslow Taylor and Frank Gilbreth, the pioneers in industrial engineering made significant contributions in the area of human effort engineering. Peter Drucker recognizes the contribution of Taylor in this area in many of his books. (Drucker, 1988) wrote, "Frederick W. Taylor was the first man in recorded history systematically to study and describe work. Taylor's 'scientific management' is a key factor in the tremendous surge of affluence in the last seventy-five years. This extraordinary change has lifted the standard of living of the working masses in the developed countries well above any level recorded before, even for the well-to-do."

Human Effort Engineering

We identified five distinct areas in the IE component of human effort engineering.

1. Principles of Motion Economy and Motion Study.
2. Work Measurement
3. Ergonomics
4. Safe Work Practice Design
5. Wage Incentives and Job Evaluation

The role of each of these techniques in the improvement of system's performance features is outlined as follows.

1. Principles of Motion Economy and Motion Study.

Motion study is concerned with the analysis of motions of workers in using production tools, handling materials or operating machines (Barnes, 1980). Fundamental human motions in the work place were specified as therbligs. The elimination and the better arrangement of motions is a part of motion study or motion design. Motion design also involves examining the relationship of the worker to the job and the environment. To support this examination a body of knowledge commonly referred to as principles of motion economy is available. These principles were first proposed by Frank Gilbreth and were refined and enlarged by other investigators. Scholars from ergonomics discipline also evaluated these principles. These principles form as a basis – a code or a body of rules – which, if applied by one trained in the technique of motion study and the problem solving process, will make it possible to increase the output of manual labour with a minimum of fatigue. Thus Barnes stated the contribution that motion study makes to a work system. It has the potential to increase the output controlled by manual operators and also minimizes the fatigue of the operators - a desirable performance measure for any work system to be incorporated in the system design itself.

2. Work Measurement

Work measurement is the application of techniques designed to establish the time for a qualified worker to carry out a task at a defined rate of working (Kanawaty, 1995). Work measurement also specifies the time taken by a machine to complete the work on a job. It also specifies the take taken for producing a fully finished component or product. Work measurement provides the following benefits in system design.

(i) The measurement is used for comparing the efficiency of alternative methods for selecting the most efficient method to be incorporated into the system. Other conditions being equal, the method which takes the least time will be the optimal method.
(ii) The measurements of various activities are used in balancing the work of team members and in the reduction of throughput time for the team task.
(iii) The measurements are used in determining the number of machines an operator can manage in the case semi-automatic and automatic machines.
(iv) The measurements help in production planning.
(v) Cost estimating is made more accurate.
(vi) The measurements are used for assessing the progress of trainees on various tasks.

Thus work measurement provides the basic information necessary for all the activities of organizing and controlling the work of an enterprise in which the time element plays a part. It evaluates the capacity of the proposed work system. Work measurement techniques range from stop watch time study to advanced predetermined motion time systems (PMTS) like MOST. Using work measurement techniques to select the best methods for various activities in a work system is to be the preferred approach to optimize the systems.

3. Ergonomics

Dongjoon Kong (Kong, 2006) has written that the purpose of industrial engineering is to seek an optimal solution under given conditions. Dongjoon Kong also stated that human factors engineering is one of the main areas of industrial engineering. Human factors and ergonomics are synonymous terms. (Sanders and McCormick, 1993) have stated that engineering psychology is positioned by some as basic research on human capabilities and limitations and ergonomics or human factors engineering as the application of the information to the design of things. Industrial engineers use the knowledge of ergonomics in design of work systems. They integrate the requirement of human force and power with the recommendations of human factors specialists or ergonomists to come out with an optimal solution to the man machine integration and human effort design. The utility of incorporating various occupational safety and health guidelines into the work systems is well appreciated now and industrial engineering department is to be entrusted with this work during the system design phase.

4. Safe Work Practice Design

Industrial engineers have to make work productive. At the same time they have to ensure that the operators use right protective equipment like gloves, goggles, shoes, and helmets. These safety devices are to be incorporated into standard work practices and operators are to be given training in their respective trades with using all safety devices and work measurements also have to reflect use of the safety devices. Safe work practice design has to be in the system right from day one of systems operations.

5. Wage Incentives and Job Evaluation

Production incentive systems are at least 100 year old practice in recorded business management history and science. Many of

these incentive systems have provided benefits to the companies that implemented them and the employees who worked under them. They addressed the common needs of employees and employers. Employees want to know what is expected of them. Incentive goals or standards provide this information and fulfill the need. Employees also feel a greater sense of accomplishment when their achievement of the goal is recognized in the pay cheque in incentive systems (Weiss, 2001). From the employer's viewpoint, increased production per period lowers unit labour costs and provides them competitive advantage. Wage incentive systems can be installed from the beginning in work systems.

Job evaluation is the process of converting job content and job responsibilities into a rationale for a job hierarchy for base pay structure design (Davic, 2001). It needs to be done during the design phase of the systems employing people.

All the five techniques of industrial engineering classified under human effort engineering have a role to play in the systems design phase and industrial engineers are to be involved to analyze and incorporate the principles underlying these techniques into work systems during the design phase.

System Efficiency Engineering

System efficiency engineering is the second core function of industrial engineering function. The techniques classified under this component of industrial engineering are:

1. Method Study and Methods Design
2. Value Engineering
3. Statistics Based Techniques: Statistical Quality Control (SQC), Statistical Process Control (SPC), Statistical Inventory Control and Six Sigma Projects etc.
4. Operations Research and Quantitative Techniques
5. Plant Layout Studies for reduction of material movement, operator movement and movement of salesmen etc.
6. Engineering Economics
7. IE Solutions in Specific Functions: Single Minute of Exchange of Dies (SMED), Lean Production Systems and Gantt Charts etc.

1. Method Study and Methods Design

Method study is the systematic recording and critical examination of ways of doing things in order to make improvements (Kanawaty, 1995). From an industrial engineering point of view, productivity and resource use minimization are key focus areas. Process analysis and operation analysis form part of method study. Motion study is also included as a part of method study, but we included motion study as an important activity in human effort engineering as it has its prime focus on motions of human limbs. The methodology of method study is rationalization of proposed methods. Each and every operation proposed is subjected to scrutiny to ensure that the best possible alternative was chosen for doing an operation, the place of doing, the equipment used for doing it and the time chosen for doing it. It thoroughly evaluates a proposed system to make it optimal rather than a satisfactory solution. Method study is to be recommended during system analysis and optimization phase of any system.

2. Value Engineering

Value analysis or value engineering is an organized creative approach which has for its purpose the efficient identification of unnecessary cost, i.e., which provides neither quality nor use nor life nor appearance nor customer features. This is the definition given by L.D. Miles (Miles, 1972) for the technique

developed and promoted by him. Value analysis results in the orderly utilization of alternative materials, processes and specialized suppliers. It focuses engineering, manufacturing and purchasing attention on one objective – equivalent required performance for lower cost. Value engineering is based on creation of database of functions and alternatives in terms of relative costs and optimizing the value of the finished product from a work system. The utility of implementing value engineering in design phase of products and work systems is better appreciated now and in systems using target costing, value engineers are made part of the design team. Value engineering analysis of systems is to be recognized as an important part of system design process.

3. Statistics Based Techniques: Statistical Quality Control (SQC), Statistical Process Control (SPC), and Six Sigma Projects etc.

Industrial engineering draws upon specialized knowledge and skill in the mathematics and related subjects to improve work systems. This point was incorporated in the definition of industrial engineering itself. Statistical quality control and statistical process control are standardized techniques in the area of application of statistics in system efficiency engineering and recently six sigma became a popular technique delivering benefits in system performance improvement. Statistical quality control and process control systems can be installed during the design phase of systems.

4. Operations Research and Quantitative Techniques

Quantitative techniques and operations research (OR) models help in developing optimal systems in relation to many dimensions. Optimization encompasses such areas as the theory of ordinary maxima and minima, the calculus of variations, linear and nonlinear programming, dynamic programming, and game theory etc. (Ibidapo-Obe and Asaolu, 2006). The subject is now well developed with many models and refinements to the models and applications to various situations that one encounters in work systems and business systems. Industrial engineers by their background in engineering are close to the engineering systems and they can extract the data required to operationalise the models proposed by OR model developers. While the development of models is the focus of mathematicians and statisticians, evaluation of the model for its practical utility and developing the data required to operate the model in organization has to be the responsibility of industrial engineers. Industrial engineering needs to take the responsibility for converting the OR models into cost savings or revenue improvement for the organizations. Many OR models can be applied during the system design stage itself and industrial engineers are to be given the mandate to analyze the system architecture for optimization using OR models.

5. Plant Layout Studies for reduction of material movement, operator movement and movement of salesmen etc.

This is an old technique of industrial engineering. This technique is described in work study books also. But full texts are available for facilities planning and layout design in industrial engineering series of books. The focus of industrial engineering is on minimization of material movement and operator movement. The objective is to reduce material handling cost. There are quantitative techniques to choose a site for production or warehouse facility (Patel, 2001), various computer assisted models to select the best layout (Wrennali, 2001), and there are methods to form optimal group technology cells. All these techniques are to be employed

at the system design stage itself to have the most efficient system in place.

6. Engineering Economics

Engineering economics is comparison of economic results of engineering alternatives with a view to select the most economical engineering solution. Engineering solutions are visualized by engineers or technical personnel only, but selection of the most economical solution is needed to develop cost-effective systems and engineers have to apply engineering economic methods and they are to be supported in this activity by specialists as required. Industrial engineering discipline has a special role to play as industrial engineers specialize in making systems profitable. Industrial engineering has engineering orientation and business orientation simultaneously. It is a discipline that evolved out of involvement of engineers in managing commercial production establishments. Industrial engineering department has to undertake the engineering economic appraisal of the system proposed at the system synthesis or architecture stage and ensure that the most economical engineering design was brought into existence (Riel, 1998).

7. IE Solutions in Specific Functions: Single Minute of Exchange of Dies (SMED), Lean Production Systems and Gantt Charts etc.

Industrial engineering is applicable to various sectors of the economy like agriculture, mining & manufacturing and service businesses. Also, it is applicable to various functions in a business organization like production, maintenance, and marketing etc. During the many years of applying generic IE techniques to various functions, industrial engineers came out with certain unique methods applicable to certain functions. Single Minute of Exchange of Dies (SMED) is one of the important innovations of this kind. Industrial engineering studies of the processes of changing dies resulted in a drastic reduction in the time required to change the dies to less than 10 minutes. This reduction in set up time of dies reduced the batch quantities dramatically leading to lean production systems. Now these methods or techniques can be incorporated into systems at the design stage itself.

Thus we find that the five techniques, discussed under the head of human effort engineering and seven techniques, described in system efficiency engineering provide us with an initial list of twelve tools or groups of tools which can be used during the system design stage to make systems efficient. It is interesting to note that systems engineering has as its responsibility achieving balance among subsystems and multiple disciplines in the system design process (Sheard and Mostashari, 2009). Systems engineering discipline has to recognize the importance of industrial engineering in making systems efficient and provide a role for the discipline in system design process. The paper emphasizes that IE is one of the specialty engineering techniques applied in systems design and advocates that systems engineering process descriptions must include IE as an important specialty engineering discipline to be involved in the system design.

Conclusions

Industrial engineering is composed of number of techniques which are to be used during the system design phase. Ideally, they are to be used to analyze the design or architecture proposed during the system synthesis phase. They, therefore, fall under the system analysis and optimization phase. Industrial engineering of systems is a useful term to denote the use of industrial engineering techniques during system design stage and this paper brought out the relevance of IE techniques during systems design

adequately. We strongly advocate the use of the term 'Industrial Engineering of Systems' as well as the use of IE techniques to make systems optimal during the design stage.

References

Badiru, Adedeji B. (Ed.), *Handbook of Industrial and Systems Engineering*, CRC Taylor and Francis, Boca Raton, 2006.

Barnes, Ralph M., *Motion and Time Study: Design and Measurement of Work*, John Wiley & Sons, New York, 1980.

Davic, Nicholas D., "Job Evaluation", Chapter 7.2 in Zandin, Kjell B. (Ed.), *Maynard's Industrial Engineering Handbook*, Fifth Edition, McGraw-Hill, New York, 2001.

Drucker, Peter, *Management; Tasks, Responsibilities, Practices*, HeineMann Paperback, 1988, Oxford, p.171.

Ibidapo-Obe, Oye, and Asaolu, Sunday, "Optimization Problems in Applied Science: From Classical through Stochastic to Intelligent Metaheuristic Approaches", Chapter.22 in Badiru, Adedeji B. (Ed.), *Handbook of Industrial and Systems Engineering*, CRC Taylor and Francis, Boca Raton, 2006.

IIE, http://www.iienet2.org/Details.aspx?id=282, Accessed on 1.2.2010.

INCOSE, http://www.incose.org/practice/whatissystemseng.aspx, Accessed on 1.2.2010.

Kanawaty, George (Ed.), *Introduction to Work Study*, Fourth Edition, Universal Publishing House, Bombay and ILO, Geneva, 1995.

Kong, Dongjoon, "Human Factors and Ergonomics", Chapter 2 in Badiru, Adedeji B. (Ed.), *Handbook of Industrial and Systems Engineering*, CRC Taylor and Francis, Boca Raton, 2006.

Martin, James, N., *Systems Engineering Guidebook: A Process for Developing Systems and Products*, CRC Press, Boca Raton, 1997.

Miles, L.D., *Techniques of Value Analysis and Engineering*, Second Edition, McGraw-Hill, New York, 1972.

Narayana Rao, K.V.S.S., "Definition of Industrial Engineering: Suggested Modification", *Udyog Pragati*, October-December 2006, pp. 1-4.

Oke, S.A., "An Overview of Industrial and Systems Engineering", Chapter 8 in Badiru, Adedeji B. (Ed.), *Handbook of Industrial and Systems Engineering*, CRC Taylor and Francis, Boca Raton, 2006.

Patel, Raj M. "A Quantitative Approach to the Site Selection Process", Chapter 8.1 in Zandin, Kjell B. (Ed.), *Maynard's Industrial Engineering Handbook*, Fifth Edition, McGraw-Hill, New York, 2001.

Riel, Philippe F., "The Role of IE in Engineering Economics", *IIE Solutions*, April 1998, pp. 32-38.

Sanders, Mark S., and McCormick, Ernest J., *Human Factors in Engineering and Design*, Seventh Edition, McGraw-Hill, New York, 1993.

Sheard, Sarah A., and Mostashari, Ali, "Principles of Complex Systems for Systems Engineering", *Systems Engineering*, Vol. 12, No. 4, Winter 2009, pp. 295-311.

Weiss, Roger M., "Reengineering Production Incentive Plans", Chapter.7.4 in Zandin, Kjell B. (Ed.), *Maynard's Industrial Engineering Handbook*, Fifth Edition, McGraw-Hill, New York, 2001.

Wrennali, William, "Facilities Layout and Design", Chapter 8.2 in Zandin, Kjell B. (Ed.), *Maynard's Industrial Engineering Handbook*, Fifth Edition, McGraw-Hill, New York, 2001.

Biography

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