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Strategic Solutions: How Mathematics Reshapes Industrial Landscapes

T.R. Vijayaram[1,*], [2]N. Ramya

Abstract

One of the earliest and most fundamental fields of the physical sciences is mathematics. It has a significant impact on industrial enterprises' bottom lines and enhances their performance in the current data-driven market. One subfield of applied mathematics is industrial mathematics. It concentrates on issues that arise in the industry and seeks answers that are pertinent to the sector. The use of mathematical models and techniques to diverse industry difficulties has garnered a lot of interest lately. Statistics, trigonometry, dynamics, optimization, and mathematical modeling approaches are all used in industrial algebra. Applied mathematics is a subfield of algebra that focuses only on practical applications and includes the study of computational and physical sciences. It is heavily utilized in computer science and engineering and is based on numerical techniques. A relatively recent area of mathematics research called "industrial mathematics" focuses on using mathematical modeling to solve practical issues in the real world, providing the groundwork for the creation of new technologies. It includes both pure and practical mathematical modeling, including dynamics, discrete mathematics such as calculus, likelihood, statistics, and partial differential equations. To put it another way, it will combine and restructure applied and pure mathematics into a dynamic form that can effectively meet the demands of diverse industries. In contrast to other sciences, industrial mathematics focuses on industry problems and seeks to identify pertinent solutions, including the most economical and efficient approach to address the issue. The need for mathematical skills is growing daily due to the intricate and advanced nature of today's industries. The newest computer techniques, computer graphics, system reliability software testing and verification, or databases can all be used to develop solutions through mathematical models. The function and applications of algebra in industry are covered in this summary study.

Keywords: industrial mathematics, Industry, statistics, Mexican manufacturing, database

***Author for Correspondence**
T.R. Vijayaram
E-mail: vijayaram.mech@bharathuniv.ac.in

[1]Professor, Department of Mechanical Engineering, School of Mechanical Engineering, BIST, BIHER, Selaiyur, Chennai, Tamil Nadu, India
[2]Professor, Department of Mathematics, SHSS, BIST, BIHER, Selaiyur, Chennai, Tamil Nadu, India

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INTRODUCTION TO INDUSTRIAL MATHEMATICS

Among the sciences, mathematics is the most applied. It is in a unique position to adapt quickly to the needs of a changing economic environment. Sadly, there is a lack of correlation between academic mathematics and the mathematics applied in industry, which makes it challenging to establish stronger ties with industry. Therefore, there needs to be a stronger balance between theory and application in academic mathematics science [1]. A relatively recent area of mathematics research called "industrial mathematics" focuses on using mathematical modeling to solve practical issues in the real world, providing the groundwork for the creation of emerging technologies [2]. Discrete mathematics, probability, statistics, the use of partial differential equations, as well as many more topics are included in this blend of pure and applied mathematical modeling. To put it another way, it will combine and restructure applied and pure mathematics into a dynamic form in order to meet the demands of industrial technology. Let's look at a case study of a Mexican corporation that filed a complaint about the air conditioning fan noise coming from the automobile seat. They were suffering a significant loss since customers were returning their goods due to an unwanted noise. They were unclear on the type of noise that was inappropriate. Despite extensive investigation, the Mexican manufacturing facility's definition of unwanted noise differed from that of the client plant. Mathematicians came to their aid in this situation. Using a specialized microphone and computer, they assessed the noise frequency spectrum. They then looked into which frequencies were bothersome to people's hearing, statistically evaluated the noise spectrum, and identified the frequency bands that the client company found unwanted. Subsequently, they developed a computer program that could autonomously ascertain whether or not an object is flawed. This was one of the instances where mathematicians' contributions to industry were advantageous [3]. From the case study above, it is clear that the basis for technical and economic advancement will be the ability to apply mathematical modeling, simulation, control, and optimization successfully. This will aid in improving our understanding of industrial models and processes [4].

CONCEPTS OF INDUSTRIAL MATHEMATICS

Subsequently, they developed a computer program that could autonomously ascertain whether or not an object is flawed. This was one of the instances where mathematicians' contributions to industry were advantageous. From the instance discussed above, it is clear that the basis for technical and economic advancement will be the ability to apply computational simulation, control, and optimization successfully. This will aid in improving our understanding of commercial structures as well as processes. As would be expected, IMA draws from a wide range of mathematical fields, including discrete mathematics, partial differential equations, dynamic systems, control theory, probability and statistics, and probability and statistics. The objective of using mathematical concepts and computations to better understand industrial models and processes unites all of these endeavors [5]. Industrial numbers' primary goals are to comprehend real-world industrial use problems that were first expressed in non-mathematical terms, translate them into a suitable mathematical framework, identify potential solutions for these problems using appropriate techniques that may be analytical, numerical, or both, test the reliability, reliability, and validity of the solutions, and, finally, interpret or apply the realizations in terms of the original real-world industrial problems. IMA addresses the issues in the following sequence in this manner (Figure 1):

Reality → Mathematical Model → Solution → Interpretation → Reality

Figure 1. Flow chart of. IMA addresses.

Industrial scientists serve as a bridge between mathematics and the real world. In reality, they attempt to apply distinct concepts and techniques from the mathematical domain to address real-world issues from various businesses, organizations, and industries. Given the diverse applications of these problems, it is challenging to determine which mathematical techniques are most suitable for resolving the current issues [6]. This implies that depending on the nature of the issues, there are multiple approaches to solving industrial challenges. Among computing techniques or instruments to address industrial problems include partial differential equations, mechanics, statistical and probability theory, mathematical modeling, simulation, discrete and continuous optimizations, numerical approaches, etc. The key areas of research in this field include the exploration of novel concepts, procedures, algorithms, applications, and the evaluation of their reality. The primary driving forces behind IMA are the real-world and applied issues that arise in society and provide mathematicians with new and difficult challenges. The involvement of industrial mathematicians in the field of high technology has expanded due to the construction of increasingly powerful computers, robotics, flexible machine systems, etc. The Division of Probability and Statistics at CSIRO in Australia; Mathematical Methods in Industrial

Problems in Italy; the European Consortium for Mathematics in Industry (ECMI) in France, the UK, Sweden, Germany, and other countries are only a few examples of the modern applications and advancements of IMA. India Society for Industries and Applied Mathematics; Institute for Industrial Mathematics, Israel; Industrial Mathematical Modeling (IMM), England; Industrial Mathematics Competence Center (IMCC), Austria; The Netherlands, Norway, Denmark; Society for Industrial and Applied Mathematics, India (SIAM); These illustrations demonstrate how thoroughly the concepts and goals of IMA have been investigated [7].

It is naturally extremely difficult to group practical problems relating to electricity, fluid dynamics, elasticity, electromagnetic field, heat conductivity, production planning and manufacturing processes, scheduling of vehicle and airline routes, quality control, pollution, environment, water distribution flows and matching, transportation, communication, chemical processes, cell biology, and so on into a single class of problems because there are so many different types of interdisciplinary areas (such as industrial statistics, economic mathematics, insurance mathematical information, operations research, partial differential equations computational mechanics, control theory, progressed calculus, modern optimization, etc.) within the umbrella of industrial use mathematical theory. Our goal in this paper is to provide some inspiring examples of industrial or applied mathematics as well as certain social phenomena models and difficulties [8]. Applied mathematicians tackle a wide range of issues. Industrial mathematicians and statisticians, for instance, have encountered and resolved the following issues in the workplace:

- Why is a car manufacturing facility operating well below its intended capacity?
- How should the price of tickets be set by an airline to maximize profits while accommodating no-shows, the annoyance of overbooking, and other costs?
- Which credit card collecting tactics result in the highest long-term revenue?
- Just as photos are “printed” from a negative, computer chips are also “printed.” However, the cost of producing the “negative” prevents cut-and-try testing of suggested patterns and the associated “print.” Exist precise mathematical representations of the exposure process? Can these be used with effective computational methods to produce realistic, affordable simulations that help with semiconductor design and production?
- Chemical manufacturer must shift one of his product lines to a new family of compounds that will not harm the ozone layer. Since he cannot test possible new products by releasing them into the atmosphere, it must develop models of atmospheric chemistry that simulate the complex chemical reactions in the atmosphere, the action of the sun etc. Can computational simulations show sufficient detail to capture the effect of the chemicals but still be fast enough to permit studies of many different chemicals?

Industrial mathematics has been used to validate designs prior to manufacture, test plants prior to construction, and provide an explanation for process failures. Numerous areas of the pure and/or social sciences, engineering, and industrial applications commonly use mathematical modeling, numerical methods and simulation, asymptotic analysis, structural analysis, stability analysis, etc [9].

Numerous innovations resulting from the interplay between mathematics and other disciplines have been made possible by the swift advancement of science and technology. For instance, as the nature of their solutions has come to light, nonlinear partial differential equations and stochastic processes—once the focus of theoretical mathematics research—are now being exploited as potent tools for the processing of images. Additionally, as computer speed has advanced dramatically, more precise and effective numerical techniques have been created, and numerical simulations that use large-scale computations are offering effective tools for real-world issues. Since mathematics serves as the cornerstone for so many other academic fields, there are far more workers who employ mathematical approaches than there are people who are officially classified as mathematicians. Physicists, engineers, computer scientists, and economists are a few professions that heavily rely on mathematics. A specific area of mathematics is actually their area of expertise. Examples of such experts are statisticians, actuaries, and operations research analysts. Applied mathematicians are frequently called upon to cooperate with other members of their workforce in order to arrive at shared solutions for industrial challenges [10].

Selecting the optimal configuration or collection of parameters to accomplish a certain goal is a crucial optimization problem involving both continuous and discrete variables in several real-world issues of theoretical and/or practical significance. Finding the problems, turning them into mathematical models, and creating the algorithms for the problems' numerical solutions are the three main goals of mathematical programming [11–13]. While modern optimization techniques were primarily developed following World War II and with the advancement of modern computers, classical techniques, such as calculus methods and calculus of variations, were developed in the seventeenth and eighteenth centuries by Newton, Cauchy, Euler, and Lagrange. The two primary pioneers of contemporary optimization are Kantorovich L. V. (1939) and Dantzig G. B. (1947), who provided the Graphical and Simplex algorithms, respectively, for solving Linear Programming (LP) problems. R.E. Gomory created integer programming (IP) in 1948, and nonlinear programming (NLP) problems, which address a broader spectrum of real-world issues, were created in the mid-1950s to early 1960s. It is challenging to find suitable answers for the majority of NLP problems in an acceptable length of time.

INTERACTION BETWEEN MATHEMATICS AND INDUSTRIES

Different scales of industry problems that greatly benefit from mathematics are observed. Particular issues when existing techniques or commercial codes fall short, where a new feature needs to be added, or where the models currently on the market don't fit the bill. Medium-sized issues where a new mathematical software product needs to be introduced to the market or where the transfer of a new technology, algorithmic technique, or such has to be done. This is frequently accomplished through businesses that are spun out of academic institutions or research labs [14]. These mathematical spin-offs exhibit a high rate of market survival or are acquired by multinational corporations, resulting in the creation of innovative, highly compensated high-tech jobs. Usually, these undertakings take three to six person years. Enormous scale multi-physics, multi-scale, and multi-mathematics difficulties involve the coupling of several physical models, the application of various mathematical fields, and the almost complete lack of existing techniques. These kinds of undertakings may require 20–30 worker years.

MATHEMATICAL MODELING

An equation, or a collection of equations, that yields the state variable's time-space evolution—that is, the physical behavior of the associated physical systems within the mathematical framework—is referred to as a mathematical model. The state equation is another name for the equation that establishes the mathematical model. We must develop an analytical model for a physical or economic system, which is a mathematical depiction of the interactions between its components, before we can decide how to plan, build, or run it. Analytical models essentially fall into two categories: description and prescriptive [15]. One type of prediction model is a regression model. We can forecast the number of garage door openers we will be able to sell in the upcoming months based on the new housing starts. Conversely, physics rules are models of description; for instance, the well-known equation e = mc2 explains a physical occurrence. Each of the variables and their interactions must be precisely and quantitatively identified before we can build a mathematical programming model. Control variables and parameters are the two categories of variables. While factors are variables whose values are outside the decision-maker's control, control variables are those whose values can be allocated by the decision-maker. Verification through mathematical analysis and numerical calculation has become crucial for creating new models. The model is modified in accordance with theoretical interpretations, in-depth analyses based on numerical computations, and comparisons of these with experimental results. Simultaneously, the establishment of the model depends on these three elements working together. The following is a list of the sequential steps in the modeling technique and the corresponding analysis:

- Choosing the state variable that best describes the system's physical condition,
- The mathematical model's derivation, or the state variables' evolution equation,

- The mathematical issue is simulated, meaning that the initial or limit circumstances required for its answers are put into practice.
- Qualitative examination of the mathematical issue: presence and nature of the solutions,
- The mathematical problem's solution,
- Model validation and analysis of the outputs generated by the model.

The primary rules to be adhered to when creating a mathematical model are further explained in the flow chart that follows (Figure 2):

CONSTRUCTION AND ANALYSIS OF MODELS AND INDUSTRIAL MATHEMATICS

It is now common practice to obtain cutting edge information in the physical, biological, and social sciences by applying mathematical ideas and techniques to comprehend real-world issues coming from various fields in these disciplines. We think that the new concept of “construction and analysis of models” (see Figure 1), which takes a more comprehensive approach than the specialized “black box” modeling methodology used in most industrial R&D, is one of mathematics' most significant contributions to the study of such complex situations and problems [16]. A simplified portrayal of a portion of a real-world system or issue is what is known as a model. A mathematical model is a model that is constructed in the abstract using mathematical ideas. The required mathematical answers can be obtained by manipulating the model using mathematical theories, methodologies, or computer-aided numerical computation. After that, these solutions are rigorously verified and physically understood. By transforming these theoretical solutions into workable answers to the initial real problem, the real world is once again re-entered. Later, these solutions are applied further in the form of helpful forecasts (see this assertion and usage of this cycle of notion in Figure 3).

The topic of industrial mathematics is introduced with the goal of raising understanding and appreciation of the value of using computation, statistics, and mathematics to solve real-world industrial challenges that are not found in textbooks. Governmental organizations, corporations, businesses, and firms are all included in the definition of “industrial.”

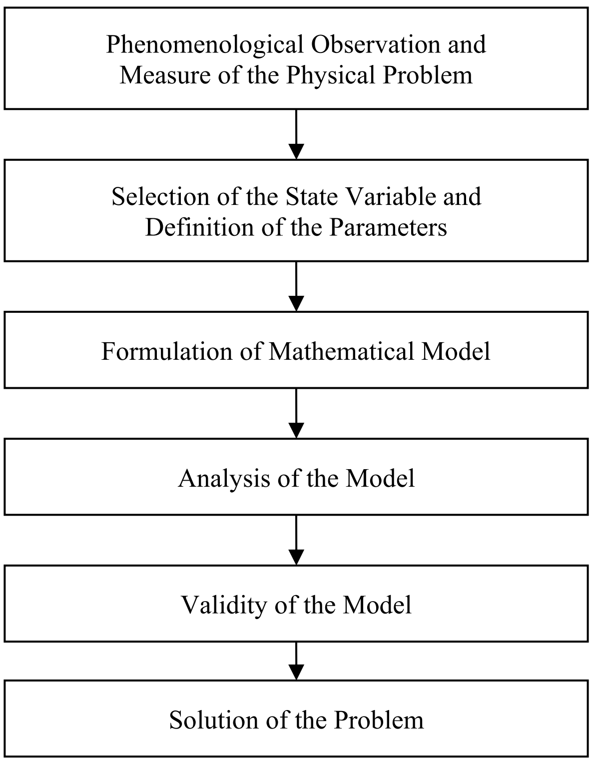

Figure 2. Flow Chart of Modeling Procedure.

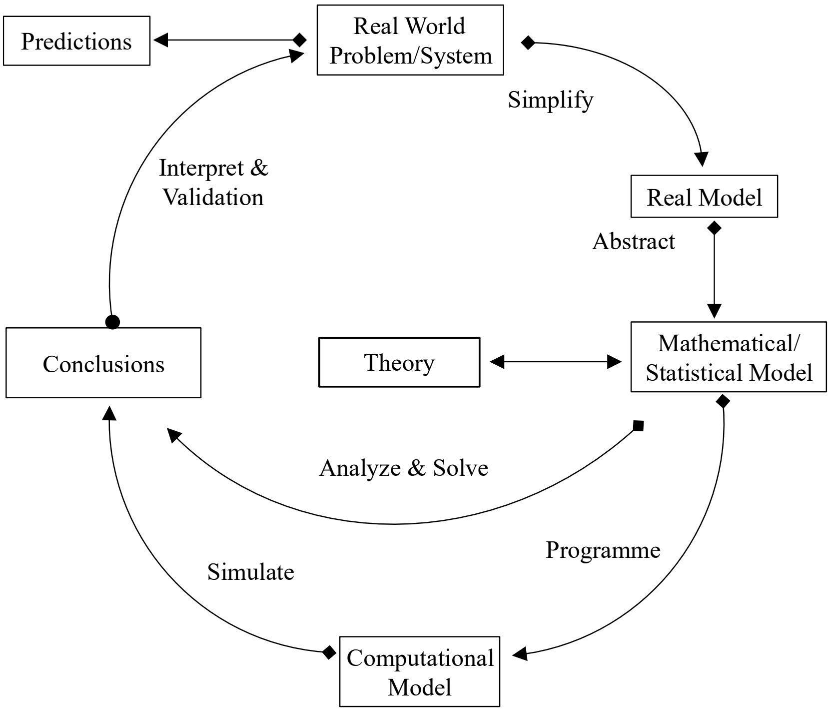

Figure 3. The cycle for the idea of "Construction and Analysis of Models [2].

Table 1. Mathematical Areas [2].

Mathematical Areas	**Application Areas**
Algebra and number theory	Cryptography
Computational fluid dynamics	Aircraft and automobile design
Differential equations	Aerodynamics, porous media, finance
Discrete mathematics	Communication and information security
Formal system and logic	Computer security, verification
Geometry	Computer-aided engineering and design
Nonlinear control	Operation of mechanical and electrical system
Numerical analysis	Essentially all applications
Optimization	Asset allocation, shape and system design
Stochastic processes	Signal analysis
Parallel algorithms	Weather modeling and prediction, crash simulation
Statistics	Design of experiments, analysis of large data sets

"Construction and analysis of models" cycle serves as a foundation for highlighting the noteworthy aspects of this particular type of mathematics. Many believe that this hallmark of industrial mathematics would increase public awareness of the ability of mathematics to provide pathways to solutions for real-world issues

MATHEMATICAL AREAS AND APPLICATIONS OF INDUSTRIAL MATHEMATICS

Not only has industrial mathematics helped to solve industrial problems more effectively. However, it has also been used to verify designs before to production, test plants before building, and provide an explanation for any process flaws that may have occurred, assisting businesses in managing risks. Signal processing, computer graphics, risk management, system dependability, software testing and verification, database systems, production line optimization, and marketing research are a few industries where industrial mathematicians can work.

The field of industrial mathematics is multidisciplinary. Stated differently, it encompasses not only mathematics but also other disciplines like commerce, computer science, engineering, etc. Although mathematics forms the basis of many other fields, there are more workers (such as engineers, computer scientists, economists, etc.) who use mathematical approaches than there are officially recognized mathematicians (such as statistics, research analysts, etc.). Put differently, applied mathematicians work together with other professionals to find shared solutions to issues. More than ever, mathematics has the potential to support quantitative comprehension of industrial strategy and operations in all business domains. Businesses who seize this chance to the fullest will have a major competitive edge. An overview of the relationship between the fields of mathematics and applications may be seen in the table to the left (Table 1):

CONCLUSIONS

The modern industrial and service industries have undergone significant transformation due to the swift advancements in science and technology. The realization and application of complex techniques (big databases, low-cost computing, etc.) to satisfy the new demand mostly depend on industrial mathematics. Additionally, because there is a significant flow of ideas in both directions, industrial mathematicians collaborate with workers from various professions to generate novel products. However, the importance of establishing and preserving professional ties between academia and industry is underemphasized. To broaden the scope of real-world problems and increase their beneficial social impact, nonacademic mathematicians should be encouraged to improve research, teaching, and application in mathematics, science, industry, and engineering. A particularly useful area of mathematics in any civilization is industrial mathematics and its applications, or IMA. Its application is considerably more widespread in the industrialized nations of Europe and the USA, but sadly, IMA's development is much slower in the developing and underdeveloped nations of Asia and Africa for a variety of reasons. It is significant, therefore, that China and India have highly developed mathematical modeling concepts. Countries of the third world should, in reality, adopt the necessary IMA knowledge for the steady development of their country, including the best possible utilization of their human and natural resources to achieve balanced economic growth. The economic standing of the nation will undoubtedly improve if Nepal is limited in its use of its water resources. It is recognized in many branches of mathematics that there is a strong bidirectional flow of thoughts and inspiration between applications and mathematics. Encouraging research, teaching, and application in mathematics, science, industry, and engineering—all of which undoubtedly contribute significantly to the general advancement of society—will require recognizing the richness of real-world applications of mathematics as well as the contributions and insights of nonacademic mathematicians.

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