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The Role and Relevance of Mathematics in the Maritime Industry

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Abstract

Maritime activities occupy more than three quarters of the world space and provide a huge occupational industry for mankind. Of late, ship construction and usage including space management onboard the vessels and the ports have brought about a great dependency on mathematical principles or models such as time series, linear programing and queuing theories among others. These models, however, hardly come in the form of direct mathematics but rather embedded in technology which, again, is built on the advancement of mathematics. This study was aimed at investigating the relevance (utility value) of mathematics in the changing trends of Maritime Business, Education and Training. The paper discusses the various domains of occupational practice where maritime education and training practitioners encounter the use and application of mathematics. It also identifies specific types or areas of mathematics applicable to and/or by Maritime Business, Education and Training practitioners in their day to day activities. The paper concludes by making recommendations for curriculum considerations on issues bordering on the mathematics teaching and learning for Maritime Business, Education and Training.

Key words: Use of mathematics, MET industry, Maritime, Mathematics curriculum.

Introduction

> "Education should be started with mathematics; for it forms well designed brains that are able to reason right. It is even admitted that those who have studied mathematics during their childhood should be trusted, for they have acquired solid bases for arguing which become to them a sort of second nature" Gouba (2008).

Mathematics has been defined in many ways throughout the ages. Today, mathematics is an inevitable part of science and it is used in almost every field of human endeavour: be it natural science, engineering, art or economics. According to Merriam Webster's dictionary, mathematics is defined as the science of numbers and their operations, interrelations, combinations, generalizations and abstractions. Again, the Britannica concise encyclopedia views mathematics as a "Science of structure, order, and relation that has evolved from counting, measuring and describing the shapes of objects". It deals with logical reasoning and quantitative calculations.

Most of university degrees require mathematics. The importance of mathematics for potential careers cannot be over emphasized. Students who choose not to take mathematics seriously or to ignore it in high school and universities forfeit many future career opportunities that they could have. They essentially turn their backs on more than half the job market. Mathematics is needed for the execution of non-routine activities such as budgeting towards our groceries and

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building projects to even accuracy in projections into the future prospects of businesses. In fact, there are huge illustrations that testify the presence of mathematics in everything that we do.

Every area of mathematics has its own unique applications to the different career options. For example, Algebra is applicable in computer sciences, cryptology, networking, study of symmetry in chemistry and physics; Calculus (differential equations) applicable in Chemistry, biology, physics engineering, the motion of water, rocket science, molecular structure, option price modeling in business and economics models (Gouba, 2008).

Industrial mathematics

Industrial mathematics is a well-established field within the mathematical sciences community. Industrial mathematics refers to all sectors of manufacturing and service, including business and engineering; and is a branch of applied mathematics. But where the applied mathematics can include theoretical topics from physics, biology, economics and computer science for example, industrial mathematics focusses on problems which come from industry and aims for solutions which are relevant to industry, including finding the most efficient (cost-effective) way to solve the problem. Applied mathematics has always been leading to important discoveries and giving birth to new disciplines.

The creation of mathematical and statistical modelling and the development of numerical methods and/or algorithms for computers to obtain solutions for problems in industry has come to be called industrial mathematical sciences or, simply, industrial mathematics. There is a current and growing demand for mathematically trained individuals who are able to move into business and industry. Numerous reports and studies carried out by professional organizations show that there is an increasing need in the work force for mathematics graduates with the practical skills to work with managers, engineers, and the like (SIAM, 2016).

Industrial mathematics is a specialty with a curious case of double invisibility. In the academic world, it is invisible because so few academic mathematicians actively engage in works on industrial problems. Research in industrial mathematics may not find its way into standard research journals, often because the companies where it is conducted do not want it to. Some companies encourage publication and others do not due to widely varied policies; and as such advisors of graduates who go into industry may not keep track of them as closely as they keep track of their students who stay in academia. Within the business world, industrial mathematics is invisible because it is often not called "mathematics". It is called "analytics," "modeling," or simply generic "research." Credit for mathematical advances may go to "information technology" when it should really go to the people who use the technology and figure out how to employ it effectively.

Industrial mathematics is an inherently interdisciplinary field. In addition to mathematics, it includes subjects from fields outside mathematics such as business, computer science and engineering, and trains mathematics students how to apply mathematical analysis to problems arising in these areas. An industrial mathematician has strong analytical and problem-solving skills built upon a background of computing, mathematics, statistics, and basic science. In addition, industrial mathematics emphasizes written and oral skills along with teamwork, skills which are valued highly in industry, but are not part of most traditional mathematics programs. Since these skills are necessary for graduates to work effectively with less mathematically inclined co-workers, they are an essential part of industrial mathematics.

With the increasing complexity and sophistication of modern industry, personnel who are able to understand technical issues, who are able to formulate precise and accurate mathematical models, who can implement solutions using the latest computer techniques, and who can convey these ideas to their co-workers who may be managers, engineers, etc. are becoming a necessary part of many organizations and companies. Examples of areas in industry that industrial mathematicians can find employment are signal processing, computer graphics, risk management, system reliability, software testing and verification, database systems, production line optimization, and marketing research.

Manufacturing and service industries have changed drastically in modern times due to the explosion in the knowledge economy. Fast and inexpensive computing, office products, and development and utilization of large databases, have necessitated sophisticated methods to meet new demands. Industrial mathematics is the enabling factor in realizing and implementing these methods. In recent years the mathematical community worldwide has responded to this growing need for mathematically trained personnel in industry. Organizations such as the Fields Institute, the Mathematics of Information Technology and Complex Systems (*MITACS*), and *Pacific Institute for the Mathematical Sciences* (PIMS) in Canada, and Society for Industrial and Applied Mathematics (SIAM) and The *National Science Foundation* (*NSF*) in the United States among others have been promoting the interaction of mathematics with industry and continue to develop ways to meet industry's demand for mathematically trained personnel (SIAM, 1996).

The above and a host of others show that mathematics stands as a huge opportunity on one hand; and a terrible stumbling block on the other, depending on how it is handled whilst in school. Every area of mathematics has its own unique applications to the different career options. For example, Algebra helps in computer sciences, cryptology, networking, and study of symmetry in chemistry and physics. Again, calculus (differential equations) is applied in chemistry, biology, physics, engineering, and the motion of water, rocket science, molecular structure, as well as option price modeling in business and economics. Again, if one wants to do a course in the physical sciences (chemistry, physics, engineering); the life and health sciences (biology, psychology, pharmacy, nursing, optometry); the social sciences (including anthropology, communications, economics, linguistics, education, geography); the technology sciences (like computer science, networking, software development); business and commerce, medicine as well as the actuarial sciences used by insurance companies, one needs a huge friendly dose of mathematics to guarantee his/her progression (Gouba, 2008).

At professional and occupational settings, mathematics plays a major role in the day to day administrative activities of management officials. For instance, the head of a container terminal in a shipping port needs to assess the space of his yard using the theory of capacity and linear programming involving resource allocation before admitting containers of various types of cargo into them. An insurance company must study the actuarial computations before the determination of payment of claims, a marriage counselor needs some knowledge in statistical rank correlation studies and Mendelian blood group mathematics to be able to scientifically prepare the would-be-couple in understanding their compatibilities, and the like.

Mathematics and the Maritime Industry

The maritime and offshore industries use advanced mathematical methods in the design of ships and mechanical analysis of offshore structures. An example is the dynamical behaviour of floating structures under wave force effects and wind conditions. Individual technical tasks like the optimal design of an anchor cable or the laying of communication cables at sea bottom leads to interesting mathematical problems. One particular challenge is the modelling of the sea and the wave conditions itself for the sake of simulation purposes (Heilio, 2004). Akakpo and Marios (2015) claimed and developed a mathematical model for the determination of collision distance and collision zone between two ensuing ships on collision course and how it could be avoided.

Maritime industries comprise companies whose activities supply innovative products and services related to the traditional maritime sector. In general, maritime industries include all enterprises engaged in the business of designing, constructing, manufacturing, acquiring, operating, supplying, repairing and/or maintaining vessels, or component parts thereof: of managing and/or operating shipping lines, and customs brokerage services, shipyards, dry docks, marine railways, marine repair shops, shipping and freight forwarding services and similar enterprises. This emerging industry also includes a significant component of traditional oil and gas and renewable energy (particularly wind, but also marine turbines) (Monfardini, et al, 2012). Indeed, a maritime industry is a centre of total human endeavour attracting professionals from all walks of life including mathematicians.

The Concept of Industrial Mathematics

Cipra (2004) reported that in 2002, Virginia Concrete, the seventh-largest concrete company in the nation, began using optimization software to schedule deliveries for its drivers. The company owns 120 trucks, which had been assigned to 10 concrete plants. However, a significant constraint is that a cement truck has roughly two hours to deliver its load before it starts hardening inside the truck. Also, the construction business is very unpredictable; typically, 95 percent of a company's orders will be changed in the course of a day. According to Cipra (2004) Virginia Concrete brought in mathematicians from George Mason University and Decisive Analytics Corporation to develop tools to automate truck dispatching. Among other changes, the mathematicians found that the company could improve delivery times significantly by moving away from the model in which individual trucks were assigned to a "home" plant. Instead, they recommended that trucks should be able to go to whichever plant is closest. Also, in overnight planning it turned out to be useful to include "phantom" trucks, representing orders that were likely to be canceled. If the order was not canceled, it could be reassigned to a real truck.

For testing purposes the company used the software to make all of the scheduling decisions; however, since system's installation, dispatchers have been allowed to override the computer. The system has enabled Virginia Concrete to increase the amount of concrete delivered per driver by 26% (Cipra, 2004). Of course, to SIAM (2012), it will be no revelation to read that mathematics can make a huge difference for private enterprises and, through them, for society as a whole. Several universities and colleges began building centers and programs in mathematics and computational science with a real-world focus. Finally, the business press has discovered the importance of mathematics, statistics, and computer science to innovation (Hardy, 2010).

The software industry is making a big bet that data-driven decision making…is the wave of the future. The drive to help companies find meaningful patterns in the data that engulfs them has created a fast-growing industry in what is known as "business intelligence" or "analytics" software and services. Major technology companies-IBM, Oracle, SAP, and Microsoft-have collectively spent more than $25 billion buying up specialist companies in the field (Lohr, 2011).

The modern toolbox of analytic and numerical method has made mathematics a real power tool for design engineers, production engineers, architects etc. One can bypass costly trial and error prototyping phases by resorting to symbolic analysis and numerical models. Mathematics is a natural tool to handle geometrical shapes, like the surfaces of car bodies and in the visualization techniques in CAD and virtual prototyping. In fact entertainment industry is one of the great clients for mathematical software nowadays. Visualization and animation is the basis of computer games and the vivid special effects in movies etc. These tricks are made possible by mathematical models. The design engineers and systems engineers have always been active users of mathematics in their profession. The possibility to set up realistic large-scale system models) and the development of modern control theory have made the computational platform a powerful tool with new dimensions.

Business analytics has become a new catchall phrase that includes well-established fields of applied mathematics such as operations research and management science. At the same time, however, the term also has a flavor of something new: the application of the immense databases that are becoming more and more readily available to business executives. Mathematical approaches to logistics, warehousing, and facility location have been practiced at least since the 1950s. The new opportunity, both for businesses and for students hoping to enter industry, lies in the development of algorithms and techniques to handle large amounts of structured and unstructured data at low cost. Corporations are adopting business intelligence (i.e., data) and analytics (i.e., quantitative methods) across the enterprise, including such areas as marketing, human resources, finance, supply chain management, facility location, risk management, and product and process design.

One cannot escape the feeling that these mathematical formulas have an independent existence and an intelligence of their own, that they are wiser than we are, wiser even than their discoverers that we get more out of them than was originally put into them. The important role that mathematics plays in our society in relationship with the many practical applications goes without saying. Regrettably, full insight into this relationship is still largely missing. The hypothesis is that with this insight, the use of mathematics will become even more effective. It will lead to a methodological approach towards design of mathematical models more than available at present.

SIAM (2016) reported that a study involving 203 mathematicians (102 master's and 101 doctoral graduates from 1988-1992) and 75 managers indicated that mathematics was a major factor in many nonacademic sector job recruitments.

Table 1 Distribution of mathematics graduates surveyed in five major nonacademic sectors of industry.

	Nonacademic sector	Ph.D.	Master's
a	Government	28%	22%
b	Engineering research, computer services, software	19%	18%
c	Electronic, computers, aerospace, transportation equipment	17%	12%
d	Services (financial, communications, transportation)	13%	22%
e	Chemical, pharmaceutical, petroleum-related	6%	2%
		83%	76%

Courtesy: SIAM (2016)

The study revealed that 28% of the PhD mathematics graduates were in government jobs, 19% in engineering research, computer services and software mathematics related jobs (Table 1). A total of 83% of PhD mathematics and 76% of the Master's holder respondents were in mathematics related jobs respectively.

According to Heilio (2004), mathematical technology is a term referring to the interdisciplinary area combining applied mathematics, engineering and computer science. Computational technology has made sophisticated mathematical methods viable for practical applications. There is a window of opportunity for mutually beneficial two-way knowledge transfer between academia and industry. This also means a challenge for the university education. The modern and dynamic view of mathematics should be reflected in educational practices. This means new kinds of expertise are called for.

Heilio (2004) stated that Industrial Mathematics is a fast growing field within the mathematical sciences. It is characterized by the origin of the problems which it engages; they all come from industry: Research and Development, finances, and communications. The common feature running through this enterprise is the goal of gaining a better understanding of industrial models and processes through mathematical ideas and computations. According to Heilio (2004) there is an approach of presenting real industrial problems and their mathematical modeling as a motivation for developing mathematical methods that are needed for solving the problems.

Mathematics and Job Prospects

According to BLS (2015), the American Healthcare occupations and industries are expected to have the fastest employment growth and to add the most jobs between 2014 and 2024. With the increase in the proportion of the population in older age groups, more people in the labor force will be entering prime retirement age. As a result, the labor force participation rate is projected to decrease and labor force growth to slow. This slowdown of labor force growth is expected, in turn, to lead to Gross Domestic Product (GDP) growth of 2.2 percent annually over the decade. The economic growth is projected to generate 9.8 million new jobs by 2024; a 6.5-percent increase between 2014 and 2024. The report further projected among others that the Computer and mathematical occupations sector will provide an increase of 13.1% by 2024 (fourth highest sector), generating an annual mean wage of $79,420,000.

Mathematics has been called the language of science (Stecke, 2005). Mathematics is used to solve many real-world problems in industry, the physical sciences, life sciences, economics, social and human sciences, engineering, and technology, for example. Mathematics was used to build many of the ancient wonders of the world, such as the pyramids of Egypt, the Great Wall of China, and the hanging gardens of Babylon. Early mathematics (computations, statistics, and accounting) has been applied to operations problems in administration and in managing technical activities, by public administrators, engineers, and managers. To Stecke (2005), the early project management techniques included project evaluation and review techniques and the critical path method. These are still used today to help manage large projects. Early mathematics (computations, statistics, and accounting) has been applied to operations problems, in administration and in managing technical activities, by public administrators, engineers and managers.

Many types of planning problems are solved using mathematics. Aggregate planning problems involve making decisions on workforce and capacity over a long period of time, say over a year's time period (Nahmias, 2005). These decisions are made assuming a forecast of demand; and they provide constraints on the actual day-to-day operations. Many such real, large, aggregate production planning problems are solved using linear programming. In automated manufacturing, a variety of planning problems need to be solved before actual production can begin. In particular, a set of part types has to be selected to be machined over some upcoming period of time. Integer programming can be used to select a candidate set of part types. Simulation or queuing models or Petri nets can be used to evaluate candidate solutions (sets of part types) according to the appropriate measures of performance.

Glover, Klingman, and Phillips (1992) provided many examples of network flow model applications. Some applications that they mentioned include electrical circuit board design, telecommunications, water management, the design of transportation systems, metalworking, chemical processing, aircraft design, fluid dynamic analysis, computer job processing, production, marketing, distribution, financial planning, project selection, facility location, and accounting. They also provided other non-industrial applications of network flow analysis, in the arts, sociology and archaeology.

Table 2: Distribution of mathematics applications in terms of business areas.

Business area	Area of mathematical application
Manufacturing	a. Dimensional tolerance, digital preassembly, and nominal components b. Modeling of manufacturing systems, reactive ion etching, and thermal processes c. Pattern placement and throughput in electron beam technology d. Process optimization (reducing time to market)
Product design	a. Shape optimization b. Simulation of functionality c. Programming the market impacts, etc.
Materials	a. Predicting damage and degradation of polymers b. Nondestructive testing c. Simulation of material properties
Environmental management	Modeling to guide decisions about hazardous products or processes
Information science	Bio-informatics (optimization, neural networks, Markov models, dynamical systems).

Courtesy: SIAM (2016)

Today's discoveries in science, engineering and technology are intertwined with advances across the mathematical sciences. New mathematical tools disentangle the complex biotic and abiotic processes that drive the climate system. Mathematics illuminates the interaction of magnetic fields and fluid flows in the hot plasmas within stars; and mathematical modeling plays a key role in research on micro and optical devices. Innovative optimization methods form the core of computational algorithms that provide decision-making tools for internet-based business information systems. It is vital for mathematicians and statisticians to collaborate with engineers and scientists to extend the frontiers of discovery where science and mathematics meet, both in research and in educating a new generation for careers in academia, industry, and government. According to SIAM (1996), there are many views about opportunities for new applications of mathematics. A selection of these, grouped by business area, is listed in Table 2.

Davis (1994) reported that recent graduates saw substantial new opportunities for mathematics in industry and government. Computing, electronics, and software engineering were listed by 32% of the Ph.D.'s interviewed, 30% listed financial analysis, 28% said engineering and 20% claimed it is operations research. Only 11% of the Ph.D.'s and 6% of the master's graduates thought that opportunities for mathematics were very limited. Davis (1994), again, reported that 59% of managers thought that there are opportunities in their own organizations for increased contributions from mathematics. Only 17% of managers thought that there were definitely or probably no additional opportunities for mathematics in their organizations.

Applications of Mathematics in Industries

The site visits, telephone surveys, and experiences of steering committee members in industry build a picture in which mathematics participates in many ways in the overall enterprise of industrial and government organizations. Table 3 indicates selected associations between areas of mathematics and applications encountered in the site visits reported by Davis (1994) two decades ago.

Table 3 Selected associations between areas of mathematics and applications encountered in the site visits.

s/n	Mathematical Area	Application
i.	Algebra and number theory	Cryptography
ii.	Computational fluid dynamics	Aircraft and automobile design
iii.	Differential equations	Aerodynamics, porous media, finance
iv.	Discrete mathematics	Communication and information security
v.	Formal systems and logic	Computer security, verification
vi.	Geometry	Computer-aided engineering and design
vii.	Nonlinear control	Operation of mechanical and electrical systems
viii.	Numerical analysis	Essentially all applications
ix.	Optimization	Asset allocation, shape and system design
x.	Parallel algorithms	Weather modeling and prediction, crash simulation
xi.	Statistics	Design of experiments, analysis of large data sets
xii.	Stochastic processes	Signal analysis

Courtesy: Davis (1994).

Mathematics is a key player in numerous success stories heard during site visits. Common themes are the technical advantages and cost savings that accrue from clever modeling, analysis, and computation by mathematicians working with other professionals. The mathematician's logical, problem-solving approach is widely seen to provide a noticeable competitive edge.

Mathematics and MET Curriculum

In general many mathematics courses in our universities are all direct lecture and sit down face-to-face assessment based. Their delivery does not involve any field experience nor field trip for industrial observation where students are confronted with industrial mathematical reality. Where students go on attachment, their focus is never on the identification of problems and the role mathematics can play in the modeling and determination of their solutions. These mathematics courses have therefore become isolated academic programmes that are just studied in the classroom, examinations taken and abandoned never to be called upon for the determination of life's challenges.

The need for mathematics and its role in the maritime industrial performance still remains more relevant than before. The introduction of modern sophisticated equipment in the operations within the maritime industry lay credence to the assertion that mathematics curriculum must be redesigned to meet these changing trends squarely, especially in the face of the rapid growth of/within the industry. Maritime Education and Training practitioners are expected to track these apparent relevance of mathematics in the maritime industry and fashion out their training curricula so as not to lag behind the world order.

As stated earlier, the modern computer/technology age has generated a need and a window of opportunity for a new kind of expertise in problem identification and solution within the maritime industry. This field could be called industrial mathematics, mathematical technology, or computational engineering. This new trend of development, if accepted, presents a challenge to the maritime educational programmes and curriculum development. Some universities already offer specialized Microsoft (MS) programmes oriented towards the professional use of mathematics. There are excellent programmes that equip the students with the skills that are needed in the mathematical projects in the Research and Development (R&D) sections in the maritime industry. In general there is still a lot of room for improvement. Pathetically, some mathematics departments have stayed too long in the pasture of isolated abstract mathematics and failed to face the challenge coming from the changing maritime world.

Conclusion

A good maritime educational package would contain a selection of mathematics, computing skills and basic knowledge of physics, engineering or other professional input. The job title in industry is very seldom that of a mathematician. It can be a researcher, a research engineer, systems specialist, or development manager. But the reality is that maritime industry is a teamwork just as industrial mathematics is teamwork. Success stories are born when a group of specialists can join their expertise and visions together in a synergic manner. The team-work makes communications skills a necessary matter. It would be very important to train oneself and others to work in a project team, where the interpersonal communication is continuously present. To become a good applied mathematician one should be curious about other areas as well, to be interested and learn basic facts from a few neighbouring areas outside mathematics. To tackle the fascinating tasks and challenges as well as developing questions in modern industry, the student needs a solid and sufficiently broad theoretical education and operational skills in the methods of applied mathematics. However, the most important single skill is the experience in modelling projects. The lectures, books and laboratory exercises are necessary, but the actual process of maturing into an expert can only be achieved by “treating real patients” with realistic dose of healing targeted medication.

Recommendations

From the point of view of successful transfer of mathematical knowledge to client maritime disciplines, mathematical modelling must be very crucial to the current educational challenges. Many departments have introduced mathematical modelling courses in the curriculum in recent years. A course in modelling may contain study of maritime case examples, reading texts and solving exercises from literature. The actual challenges and fascination are the students’ exposure to open problems, and addressing of questions arising from real maritime context. The real world questions may be found from the student’s own fields of activity, hobbies, as well as the professions of their parents. Developing a mathematically curious eye may produce an idea for a modelling exercise. A good mathematical modelling course could:

a. contain an interesting collection of maritime case studies which is able to stir students’ curiosity
b. give an indication of the diversity of maritime industrial problems and how to model their solutions
c. ensure the development of models from simple maritime issues to more sophisticated ones
d. stress the interdisciplinary nature, teamwork aspect, and communication skills involved in mathematics
e. tell about the open nature of the maritime problems and non-existence of “right” solutions
f. bring home the understanding of practical benefits in the usage of the models
g. tie together mathematical ideas from different earlier maritime related courses
h. develop and generate mathematical simulations in addressing maritime challenges.

The modelling courses could be been run in different forms. Traditional lecture course with weekly exercise session is a possibility. It would be important to implement group work mode and PC-lab activities in a maritime mathematics course. The most rewarding form of activity might be projects and weekly sessions where the students report and discuss about their work and progress on the problems. A very successful form and educational innovation is a modelling week, and intensive problem-solving workshop as has been implemented in Europe and US since late 1980s.

The supply of good classroom examples and maritime case studies from different application areas is a key factor for the development of attractive and inspiring educational modules in both applied and industrial mathematics used in the maritime industry. Especially in the courses on mathematical modelling we would need a flow of fresh problems to maintain an intellectual urge. It would be important to have ongoing contacts to different maritime sectors, professions, and diverse pockets of innovative processes. Again, new modes of assessment could be devised for the evaluation of students that make provision from regular face–to–face examinations to virtual form of assessment that allows learners to take examinations anywhere across the globe even on the high seas. Students are encouraged to give serious attention to their future. The maritime industry is competitive. A tool for competitive career is mathematics. The future is mathematics.

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