Jurnal Sains dan Matematik Vol. 2 No.2 (2010) 9 - 17
ISSN 1985-7918

An Overview of the Importance of Industrial Mathematics

Kepentingan Matematik Industri: Satu Gambaran Keseluruhan

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Abstract

Modern manufacturing, engineering and service industries have changed radically in modern times due to the explosion in the knowledge-based economy. High-speed and low-cost computing, the development and utilization of large databases to cope with this sudden need, certainly have necessitated sophisticated methods to meet new demands. We believe that industrial mathematics is one of the enabling factors in realizing and implementing these methods. In this article, it is argued that it is most advantageous to adopt a wide-ranging perspective of industrial mathematics in research and education. In particular, this can be based essentially on the novel idea of "construction and analysis of models", a more holistic approach which highlights the importance of industrial mathematics to modern industries and in teaching the programme in institutions of higher learning.

Keywords Industrial mathematics, research and education perspectives, construction and analysis of models

Abstrak

Industri pembuatan moden, kejuruteraan dan perkhidmatan telah berubah secara mendadak dewasa ini disebabkan oleh ledakan ekonomi berasaskan pengetahuan. Pengkomputeran berkelajuan tinggi dengan kos rendah, pembangunan dan penggunaan pangkalan data bagi menampung keperluan ini, tentunya memerlukan kaedah-kaedah canggih bagi memenuhi permintaan tersebut. Kami percaya bahawa matematik industri adalah faktor pemboleh bagi meralisasi dan melaksanakan kaedah-kaedah ini. Kami berpendapat bahawa adalah lebih menguntungkan jika diterima pakai suatu perspektif meluas terhadap matematik industri dalam penyelidikan dan pendidikan semasa. Secara khusus, dalam hal itu intisarinya dapat diasaskan melalui idea baru pembinaan dan analisis model yang pendekatannya lebih holistik dalam menyoroti kepentingan matematik industri kepada industri moden dan dalam pengajaran program tersebut di institusi pengajian tinggi.

Kata kunci Matematik industri, perspektif penyelidikan dan pendidikan, pembinaan dan analisis model

ISSN 1985-7918

Introduction

Mathematics underpins just about all the new technologies of science, engineering and industry. It is well accepted in most developed nations (Howson, 1995; Ewing, 1999; Rubinstein and Hughes, 2006) that mathematics is both the currency and the language of core research and development (R & D) in applied and technological fields. This includes such new frontier areas in information and communication technology, bioinformatics science, the analysis of biocomplexity and the environment, much of the socioeconomic sciences, various business and financial undertakings. This outlook is predominantly so in today's global economy as one in transition to a knowledge-based economy. As a result, many mathematicians are now becoming highly multi-skilled. They develop new mathematical technologies and apply them to solve practical problems. We think that this direct and explicit linkage between theory and applications is critical, particularly in delivering quality higher education in the universities (Friedman & Lavery, 1993).

Malaysia is among the few Asia Pacific countries that modestly seem unaware of the fundamental importance of mathematics and its applications to its future development. In our region, the governments of Thailand, Indonesia, Singapore, Australia and New Zealand have recently established research institutes to retain and apply their multi-skilled mathematicians (Wake, 2007; Zainal *et al.*, 2008). In each of these institutes, and in the many others that have been established across Asia, North America, the UK and Europe; research, higher education and public outreach are closely linked. Malaysia is still lacking far behind in terms of having a similar facility, despite having the one and only Universiti Pertanian Malaysia (UPM) – owned INSPEM (Institut Penyelidikan Matematik or Mathematical Research Institute) in Serdang, Selangor.

Moreover, other nations worldwide have started increasing their skills in the mathematical sciences, appreciating that this is one of the keys to expanding their economies. For example in the United States, the US National Science Foundation (NSF) has already begun supporting mathematics at a level which is quite unprecedented in the Foundation's past history. After many years of very low funding, which did little more than keep up with inflation, we found out that in 2002 the NSF increased its support for mathematics from USD 120 million to USD 150 million per annum. A further increase, to USD 180 million, has also been approved by Congress for 2003. And on 7 May 2002 the US House Appropriations Committee forecast an increase to USD 210 million in fiscal 2004. It was a 75% increase in just three years (Hall, 2002; and the 2002-2004 US data is reported here only for comparison purposes). This increase is certainly substantial as compared to the minuscule amount allocated ever since for all the MOHE & MOSTI's science, techno and fundamental research grants schemes, which were made available to all fields of research. For example, based on the 2008 Malaysian National Budget, the allocation for all types of research and research institutions is USD 350 million (refer Abdullah, 2007). This comparison is straightforward, i.e. we wish to show that in the U.S., there exists a specific and clear-cut funding to mathematical research only which amounted to USD 210 million in 2004, and whereas in Malaysia the allocation for all types of research is only (based on the 2008 Malaysian National Budget) USD 350 million. To our current knowledge, we do not have any data as yet to indicate the amount of a specific fund allocated particularly for mathematical research in Malaysia.

The NSF then in 2002 was not backward in highlighting the economic importance of this boost to funding for the mathematical sciences. Development of new technologies is essential to the growth of the US economy, and this goes together with the fundamental realization that mathematics is critical to that development (Ewing, 1999). Thus, in order to achieve the nation's 2020 developmental plan, Malaysia has very little choice but to emulate this NSF policy. Philippe Tondeur, then the outgoing Director of the NSF's Division of Mathematical Sciences, and the architect of the new NSF policy, notes that the extra funding is motivated by:

> "... A vital need for mathematicians and statisticians to collaborate with engineers and scientists... Technology based industries fuel the growth of the US economy, which, in turn, relies on large numbers of college graduates well versed in mathematics, science, and engineering. In our increasingly complex world, the need for broad mathematical and statistical literacy becomes ever more acute".
>
> (Tondeur, 2001)

In particular, the connection between high quality undergraduate and postgraduate education, and funding for university research in mathematics (and statistics), is vital and strong.

The Idea of "Construction and Analysis of Models" and Industrial Mathematics

The use of the concepts and methods of mathematics as an aid to understanding real world problems arising from diverse fields in the physical, life and social sciences is now a well established approach to gaining frontier knowledge in these areas. We believe that one of the most important contributions that mathematics makes in the study of such complex situations and problems is through the novel idea of "construction and analysis of models" (refer to Figure 1), a more holistic approach as compared to the mere custom-made "black box" modelling methodology of prevalent industrial R&D.

Any model can be defined as a simplified representation of certain aspects of a real world system or problem. A mathematical model is a model created in the abstract world using mathematical concepts, and manipulation of the model via mathematical theories and techniques or computer-aided numerical computation would provide the necessary mathematical solutions. These solutions are then physically interpreted and strenuously validated. The real world is re-entered by translating these theoretical solutions into practical solutions to the original real problem, and later put to further applications in the form of useful predictions (refer this claim and use of this cycle of idea of Figure 1, e.g. modelling of Tsunami waves in Nazeeruddin *et al.*, 2008; modelling of nonlinear waves in Faisal & Zainal, 2009; modelling of earthquake waves in Dennis *et al.*, 2010). Alternatively we could propound a statistical model instead, after gathering much data from the real life problem. The corresponding cycle of idea then follows suit. The same applies to any man-made real engineering and industrial problems that are; any model can be defined as a simplified representation of certain aspects of these real man-made systems (Zainal, 2008).

Jurnal Sains dan Matematik Vol. 2 No.2 (2010) 9 - 17
ISSN 1985-7918

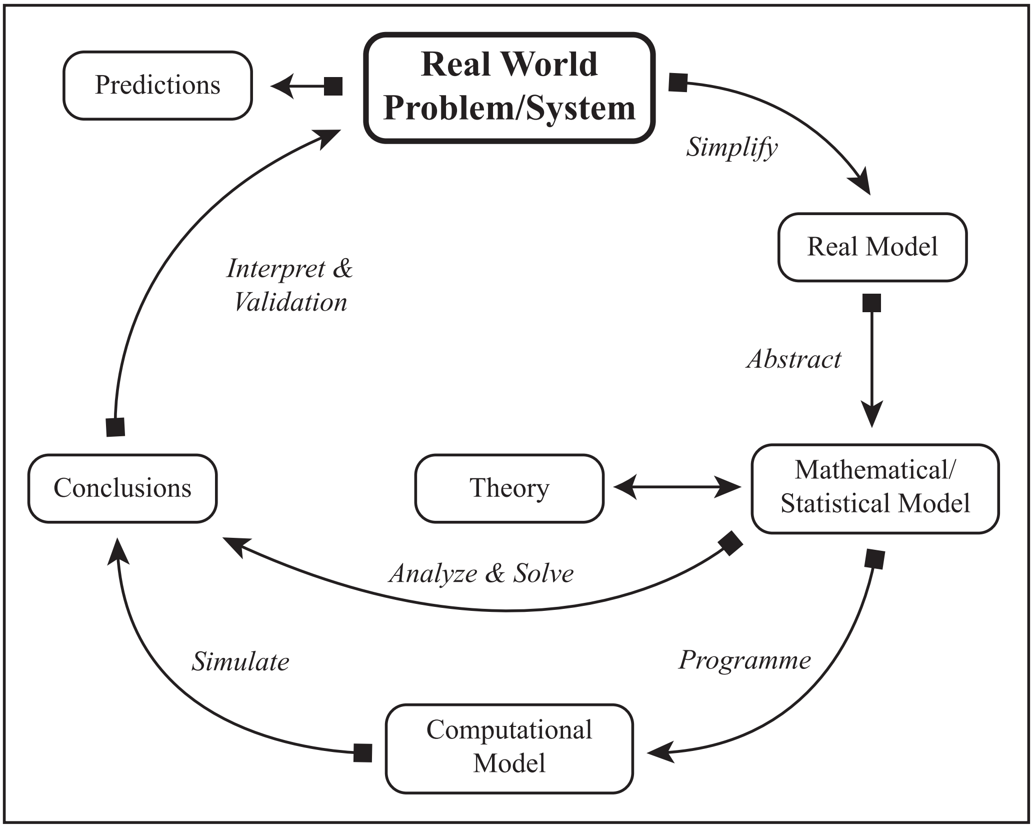

Figure 1 The cycle for the idea of "Construction and Analysis of Models

To increase the awareness of and appreciation for the effectiveness of the applications of mathematics, statistics, and computational procedures to solving real industrial problems of a "non-textbook" nature, the field of industrial mathematics is introduced. The word "industrial" is used to include corporations, businesses, firms, and government agencies. As we have stated earlier, the notable nature of this brand of mathematics can be brought to fore through the cycle of the approach of "construction and analysis of models", as entrenched in Figure 1. Many are of the opinion that this trademark of industrial mathematics would stimulate greater awareness in the wider community of the power of mathematics in providing solution paths to real-world problems (David Junior, 1984 and also see http://www.maths-m-industry.org.)

Overview of the Importance of Industrial Mathematics

Research Perspective

In broad terms, industrial mathematics is the extension of applied mathematics to industrial applications. In specific terms, though industrial mathematics is a branch of applied mathematics, but the latter can include theoretical topics from physics, biology, economics and computer science for example, whiles industrial mathematics focuses on problems which come from industry and aims for solutions which are relevant to industry, including finding the most efficient (i.e., cost-effective) way to solve the problem (see many examples of these solvable industrial problems in Neunzert, 2006). This is the reason why industrial mathematics in this new millennium becomes an indispensable key in emerging technology fields from several investigations in Europe (see Cliffe *et al.*, 2004 and Neunzert and Trottenberg, 2006). These up-and-coming fields include simulation of processes and products; optimization, control and design; uncertainty and risk; management and exploitation of data; virtual material design; biotechnology, food and health. Thus nurturing university-industry relations as pathways to innovative R & D and high quality education is inevitable (the importance of this relationship is discussed critically in Miller & Le Boeuf, 2009, and the effective networking of university-industry via the MISG – Mathematics in Industry Study Group platform, in Wake, 2007). Based on the success of these relations in many developed nations (Wake, 2007), we think that in fostering similar trusted partnership in Malaysia would comparably in the long run provide the Malaysian industry with high-level solution paths and mathematical advice on many challenging industrial problems, whiles providing fresh research problems for the industrial mathematicians. Consequently this would exploit the expertise of these industrial mathematicians to find solutions to industrial problems and also finding state-of-the-art solution procedures for future applications.

With the increasing complexity and sophistication of modern industry, personnel (the so called "industrial mathematician") 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 presently becoming a necessary part of many organizations and companies of multinational scale. Examples of new areas are abundant in modern industry that industrial mathematicians can find employment such as in signal processing, computer graphics, risk management, system reliability, software testing and verification, database systems, production line optimization, and marketing research. On the other hand, with a suitable balanced university's education curriculum, an industrial mathematician would also be a highly sought after academic by any of the active research university's mathematics department. Thus this would definitely expand employment opportunities for the mathematics graduates.

Industrial mathematics via the approach of "construction and analysis of models" would enable mathematicians to create efficient and effective mathematical (and statistical) modelling, and together with the development of numerical methods and/or algorithms for computers to obtain theoretical and practical solutions for problems in industry (Neunzert, 2006). If we could provide similar success in obtaining solutions for industrial problems in Malaysia, as widely published in MISG proceedings for other developed nations (Wake, 2007), we deem that this would likewise stir up awareness in the Malaysian industry and business, and as well as the general public of the problem-solving power of mathematics. As a result, this would spark a meaningful trend and 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, etc. (Barton, 2002).

Educational Perspective

Industrial mathematics is an inherently interdisciplinary field. In addition to mathematics, its curriculum in the institutes of higher learning should include subjects from fields outside mathematics such as business, computer science and engineering, and should be able to train mathematics students on how to apply mathematical analysis to problems arising in these areas. A student of industrial mathematics should have strong analytical and problem-solving skills built upon a background of computing, mathematics, statistics, and basic sciences. For example, this can be fulfilled adequately via a tailor-made core course in mathematical modelling. This course is designed to coach students to construct and analyse various mathematical models associated to real life problems from diverse fields of interest, and where the cycle of idea in Figure 1 is closely put into effect.

Furthermore, industrial mathematics programme should emphasize on written and oral/communication skills along with teamwork, the generic skills which are valued highly in industry, but are not part of most traditional mathematics programmes. Since these skills are necessary for graduates to work competently with less mathematically inclined co-workers, they are an essential part of industrial mathematics. A one semester period or more of industrial training/internship is of paramount importance in any practical curriculum of industrial mathematics programme. This would provide the students opportunity to undergo the valuable actual industrial problem solving situations. This provision is made possible only when the department of mathematics has a strong and trusted collaboration with their many industrial partners, a mutual two way street. As a result, the industrial people would reciprocally monitor the curriculum so as to ensure that it is always practically useful and being continuously improved to the industry requirements.

With the above arguments in mind, the following list of recommendations would suitably go under the realm of a well-organized and competent industrial mathematics programme in highlighting the importance of industrial mathematics to modern industries, and in teaching the programme in institutions of higher learning.

a. Development of ‘relevant’ industrial mathematics curriculum and their embedded and applicable mathematical tools that might be used later in industry. The idea of ‘construction and analysis of models’ is pertinent in this circumstance and would provide innovative material for teaching courses.
b. Employing applicable mathematics that would augment industrial R & D and currently would be used in solving industrial problems.
c. Bridging the gap between academic practitioners of industrial mathematics and potential industrial users. This is made easier from results in a & b above. A credible relationship is made possible by having numerous problem solving tools to solve diverse industrial problems. This situation is made possible and can be accomplished notably via ‘win-win’ activities such as the MISG workshops (Wake, 2007).

d. Practical contribution via a pragmatic implementation of the approach of 'construction and analysis of models', in helping companies to develop and improve the commercialisation of their products.

We deem that with a suitable balanced education curriculum, generally industrial mathematicians should be able to share and realize their zones of activities and purposes undertaken in various areas as shown in the following Table 1 (IMA, 1995; Barton, 2006).

Table 1 Zone of activities and purposes in the university-industry partnership

Key Areas	**Fundamental & Strategic Research (University)**	**Applied, Technological & Industrial R & D (Industry)**
Publications	Dissemination in public domain	At times confidential/a non disclosure act
Funds	Government funds via grant applications	Private funds via contracts & deliverables
Motivation	Non profitable via spirit of enquiry & research	Normally having the desire to optimize profit making
Output	Peer reviewed journals/novel ideas/flexible time frame	At times confidential technical reports/products/strict time frame
Attitude to intellectual property (IP)	No intention in exploiting of IP	Purposeful development of IP and securing patents
Education	Very strong links to education	Few educational links generally for training & internships
Rewards	Further funding, reputation, establishment of faculty/centre of study & research	Commercial success/ further investment
Performance measures	Fellowships, growth of a centre, peer recognition, invitation to speak at conferences, public funding	Product or process improvement, development of a business, profit or national benefit

ISSN 1985-7918

Conclusions

To live up to our belief of what constitutes a programme in industrial mathematics in the new millennium, and to mobilize and undertake the programme, would surely involve a wide range organisational structure. This structure includes the university departments, research institutes, government laboratories, professional associations and hundreds of companies in Malaysia and around the world which rely notably on applications of mathematics for their commercial survival, and let alone profitability.

In other words, any active mathematics departments should develop strong scientific and industry related achievements, vigorous undergraduate and postgraduate programmes in industrial mathematics, and an exemplary track record in reaching out to industry. The creation of a mathematical research institute must have a compelling justification to assist these departments to achieve those goals. Mathematical research institutes must have a strong emphasis on interacting with industrial end-users, typically by having a balanced programme of activities on topics of industrial concern.

Government laboratories must change their mindsets. These laboratories must open up to collaboration and involvement with private and multinational companies, and thus would explicitly encourage industrial work by mandating a fraction of the budget to come from external and private funding sources. These would pave ways for heavily involved industrial applications of mathematics. The recent moves by the Malaysian Institute of Microelectronic Systems (MIMOS) Bhd in encouraging collaborative efforts with the local mathematicians are highly commendable (Karamjit, 2010). The professional associations, including the Malaysian Mathematical Science Society (PERSAMA), must be proactive in order to play a major role in influencing the culture and development of industrial and applied mathematics. These can be done by actively supporting conferences, workshops, and weekly industrial problem solving gatherings in the field of industrial mathematics.

Lastly we hope that from the above discussions, the hundreds of the multinational government-linked companies (GLC) and the private ones, who might be conscious or subconscious or still unaware of the significance of the applications of mathematics for their commercial survival, must now come to terms and appreciate that industrial mathematics is one of the keys to expand and sustain their economies and profitability.

Acknowledgements

This research was partially supported by MOHE Fundamental Research Grant, Vot. No.78082. We thanked UTM for allowing leave to present some of these materials at an invited talk at the UiTM Dungun Kolokium Matematik 2009, 21 March 2009.

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