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Big Data in Mechanical Engineering

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Big data will make its mark on technological developments in this century. It will play a key role in shaping the design of materials, products, systems, and innovations from heavy equipment and energy industry to avionics and healthcare industry. Data may well become as powerful an economic engine as the steam engine once was. Data may reconfigure industry and businesses. Additive manufacturing factories may be built next to hospitals to manufacture various supplies, and new industries may be created in the spirit of digital manufacturing.

The interest in data is not new. It has accompanied developments in science and engineering practices for centuries. The novelty is in the volume and speed with which the data is generated, its growth, and the emergence of data science.

What is Big Data?

The concept of big data can be illustrated using an Excel-like file (see Figure 1) containing process data on four parameters, temperature, flow, frequency, and status collected at one second intervals. Such a file could include many columns (e.g., from hundreds to thousands) and rows of data (e.g., from thousands to millions). The data can be numerical (e.g., the temperature parameter in Figure 1) and qualitative (e.g., the status parameter in Figure 1) the rows of the Excel file could be generated (streamed) at high frequency (e.g., 1 second in Figure 1). It is important to recognize that a big data engineer does not expect data to reside in the Excel format, as big data sets seldom exist in a ready-to-use form. Rather, data must be identified and integrated for diverse uses.

| Time | Temperature | Flow | Frequency | |
|----------|-------------|------|-----------|--|
| 13:22:01 | 130 | 25.2 | 2790 | |
| 13:22:02 | 152 | 25.1 | 2791 | |
| 13:22:03 | 165 | 33.2 | 2795 | |
| 13:22:04 | 178 | 27.7 | 2870 | |

| | | | |
|----------|-----|------|------|
| 13:22:05 | 130 | 35.9 | 2999 |
| 13:22:06 | 123 | 19.2 | 3004 |
| 13:22:07 | 111 | 25.8 | 3099 |
| 13:22:08 | 136 | 25.2 | 3123 |
| 13:22:09 | 157 | 33.2 | 3222 |
| 13:22:10 | 155 | 34.8 | 3222 |

Figure 1. Sample data set.

Sources of Big Data

Despite the proliferation of research about big data, a handful of applications may surface in which big data is readily available. Corporations store large volumes of data. However, the share size does not make data big. For example, industrial process data at a particular location may be collected for years, although the number of parameters for which the data has been collected could be limited. However, data collected at one location can be integrated with data gathered elsewhere, including public domain data.

Big data is not likely to be found in one area of mechanical engineering; rather, it can be harvested across different areas. The most powerful applications will likely emerge when data from multiple sources is integrated, e.g., material, process, manufacturing, and business data. The best quality data is usually generated by sensors, which are often arranged in networks.

Sensors and Sensor Networks – Sensors resonate in a two-fold manner within the areas of research and practice in the field of mechanical engineering. First, mechanical engineers are involved in the design of sensors for applications ranging from the measurement of flow and temperature to the measurement of wind speed and vibration. Second, many products and systems designed by mechanical engineers utilize sensors. Markets call for products and solutions that are more reliable, safer, and more dependable. This in turn creates demand for new and more accurate sensors, which measure parameters that only a few years ago were merely dreamed about. Progress in computing and data science is another factor fueling progress in sensor technology, as the data generated by sensors adds value to products.

While sensors and sensor networks are usually sources of data, certain products – for example, wind turbines – actually benefit from such data. The data generated from these sensors leads to smart products.

- **Smart Products** and systems are able to make decisions ranging from improved performance and condition monitoring to greater autonomy. Robotics, autonomous vehicles, home appliances, energy systems, and avionics will naturally benefit from sensor technology.

Smart products and devices will create The Internet of Things.

- **The Internet of Things** involves the interconnection of devices, systems, and services and goes beyond machine-to-machine communications. It covers a variety of protocols, domains, and applications. The Internet of Things extends Internet connectivity beyond traditional computers, smart phones, and tablets to a diverse range of devices and everyday things that utilize embedded technology to communicate and interact with the external environment, e.g., cars, electronic appliances, lights in households and industry, and electric car batteries.

The individual components of The Internet of Things will need their own sensory data for performance improvement. Data generated across all components will share the characteristics of big data. When collectively processed and analyzed, this consolidation of data may unleash previously unseen power through global rather than local optimization.

The operation and control of a large number of interconnected devices will require new computing paradigms. It is rather common to encounter computation platforms in industry that do not meet the big data challenge. Relational databases that have been designed for optimized usage of data storage space prevail in industry. Using a relational database to store sensor-generated transactional data, e.g., truck engine performance data, is not a good idea. Yet, this practice is widely employed in the industry. Telematics data from a fleet of trucks may lead to big data applications. However, retrieving it from a relational database is highly inefficient. Even the simplest efficient, cost-effective scheme resembling data warehouse technology, e.g., the SCADA (supervisory control and data acquisition) system, would offer tremendous benefits. Cloud computing could be the platform of choice.

- **Cloud Computing** involves deploying remote servers and software, thus allowing for centralized data storage and online access to computer services. Cloud computing considers users' preferences in providing real-time access to data. It may change the way we all communicate and store data.

Big Data at the Core of Mechanical Engineering

Sensors versed in fluids, thermal, or mechanical principles offer a promising avenue for data science applications. A large segment of mechanical engineering focuses on domains such as product design and development, manufacturing, and energy, which are likely to benefit from big data.

- **Product Design and Development** is a highly multidisciplinary process awaiting innovation. It is widely recognized that the design of an innovative product must consider data streams originating with customers, experts, the trail of data left by generations of products throughout their lifetime, and cyberspace. Markets concur through products that consider the most essential design requirements, extending beyond mere product functions. The success of Apple products is attributable to the company's expanded set of requirements.
- **Manufacturing** is continuously evolving due to the progress in process and computer technology. These changes have been reflected in a reach terminology used to describe it, beginning with flexible manufacturing of three decades ago to digital manufacturing of today. The fact is that the continuous manufacturing transformation has led to more sensors generating large volumes of data. Such data can serve various purposes. For example, mechanical engineers may improve reliability of the existing manufacturing processes, predict emerging equipment failures, design next generation of manufacturing equipment, and invent new technologies based on the historical data.
- **Energy Conversion and Economy** (The energy industry) is undergoing changes triggered largely by environmental concerns and the limited supply of fossil fuels. Energy generation is becoming distributed rather than centralized as the shift to clean energy takes place. Combustion plants and nuclear power facilities are being replaced by dozens to hundreds of wind turbines and solar panels. The existing designs of wind turbines await improvements in cost and reliability to be more competitive with fossil fuel combustors. The world awaits designs of new energy devices converting natural energy, e.g., wind energy, tidal energy, geothermal energy, solar energy, and waste energy into mechanical and electrical energy. In addition to developments in energy conversion, solutions in energy consumption are needed as well.

Energy conversion and economy systems call for greater autonomy and enhanced intelligence. A combination of design ingenuity, smart materials, and smart systems will lead to winning market solutions. These new devices will join the world of The Internet of Things.

Making a Difference

Data science offers a new paradigm of bottom-up versus top-down modeling and solving supported by the traditional physics-based approach. An engineer involved in traditional modeling (e.g., developing a finite analysis or a reliability model) looks at the problem of interest and in essence fits in the model s/he was trained to use. An engineer equipped in data science knowledge gathers historical data and uses data-mining tools to build the model of interest. If needed, s/he optimizes this data-derived model with tools such as evolutionary computation algorithms.

What Next?

Mechanical engineering is faced with a multitude of exciting opportunities. Some of these may require moving out of the usual comfort zone and embracing new materials, such as biomaterials and stem cells. The concepts embedded in fluid dynamics, thermodynamics, and mechanical systems have much to offer in understanding and benefitting from natural systems and biology. Experience in the design of energy systems may also be useful in the design of biomaterials and bio-factories that produce substances which aid in healing the human body. Additionally, data will play a significant role in understanding the underlying biology phenomena and the design of devices and systems supporting them.

Andrew Kusiak has writes about the applications of big data in design, manufacturing, wind energy, wastewater processing, healthcare, and sustainability. You can find a number of his work online categorized by [Recent Journal Papers](#) and [Research in Progress](#).