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Evolution in engineering services and logistics: decision support from the cloud

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Abstract: Decision support tools based on mathematical simulation and optimization techniques have enabled many organizations in the services economy to innovate and prosper. The rate of successful adoption by commercial and industrial enterprises, however, does not match the scale of the opportunities. Based on our experience in developing and implementing simulation and optimization solutions, we discuss the opportunities and impediments as they apply to the engineering services and logistics sectors. We then offer insight into how cloud computing concepts and technologies will increase the accessibility and adoptability of simulation and optimization tools, enabling services business to evolve at a faster pace.

Keywords: Cloud Computing, Web Services, Engineering Services, Logistics

1. Introduction

This paper looks at the application, evolution and delivery of two technologies that are vital to the services economy: simulation and optimization (SO). In the context of this paper, simulation is about creating a mathematical model of a process or system whereby outputs (items of interest) can be calculated based on a set of inputs. In optimization we go a step further and use mathematical techniques to maximize (or minimize) an output or combination of outputs given the range of inputs available and any limits that have to be respected.

We look at two areas of application:

1. Engineering Services: more specifically the operation and improvement of materials and manufacturing processes, including the design of processing equipment.

2. Logistics: more specifically planning and scheduling in logistics networks.

These are essentially applications of decision support, where the user can explore options quickly and consistently, focusing on making the best decision and spending a minimum amount time generating, screening and evaluating options.

SO are CPU-intensive and require and create large amounts of data, consequently requiring significant IT resources. Cloud Computing is a relatively new delivery option for IT resources which is growing rapidly (Gartner, 2011). It has the potential to provide cost-effective, scalable resources for enterprise applications (Linthicum, 2009) and scientific applications (Lin et al., 2009 and Vecchiola et al., 2009). SO are elements of business innovation and scientific discovery, depending on the user and the context. With simulation, designing a new piece of equipment may be business innovation for equipment designers, but it is also discovery as insight is generated into physical phenomena.

Based on the characteristics of SO, we believe that Cloud Computing is a logical evolution for service delivery of these technologies. SO should benefit from improvements in performance and cost savings as users and software providers adapt their software and working practices to get the most out of this new technology.

2. Engineering Services

Process improvement and equipment design are areas where application of engineering expertise can reduce cost, improve capacity and reduce environmental impact. While a lot of progress has been made there is still much opportunity and need for improvement. For example, it is estimated that the efficiency of comminution (grinding) is less than as 5% (Khumalo et al., 2008; Cleary and Morrison, 2011) with the commonly held belief that it is of the order of 1%. Grinding typically consumes around 50% of the total energy used in hard rock mineral processing (Nauze and Temos, 2002). It is further believed that the total energy used in all such mills is of the order of 5-10% of world energy consumption. This represents a significant cost in the production of metals and is a major contributor to Greenhouse Gas formation. So there is significant potential for improvement and consequently the economic and environmental efficiency of the mill.

Particle based simulation (DEM and SPH) have been pioneered by CSIRO for the last 22 years. They deal with complex particle and fluid flows, predicting the behaviour of every particle and every piece of fluid in three dimensional space and all their collisions and interactions are individually modelled. For particulate flows, DEM is the only approach that is able to accurately predict flow behaviour (Cleary. 2004, 2009). The SPH method has strong advantages compared to traditional Computational Fluid Dynamics (CFD), particularly for high speed or splashing free surface flows (Cleary et al. 2007).

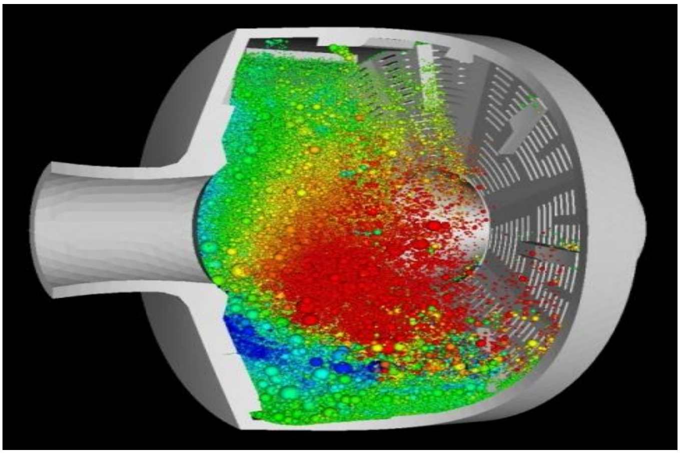

Figure 1: Particle flow in a tumbling mill.

Figure 1 shows an example of a DEM model of an industrial tumbling mill used for hard rock grinding in metal production. Particles are forced to rotate by the large lifters attached to the shell, rise to the highest point and then free fall down to the free surface. Collisions progressively break down the rock until it is small enough to liberate the valuable mineral from the waste rock. Significant energy is expended breaking rock that is not part of the product and producing ultra-fine particles that are too small for separation. Changes to the operating conditions of the mill and changes in the design of the mill can be investigated computationally to observe the effects on mill energy consumption, wear and particle breakage without having to fabricate liners and interrupt production.

The advantages of modeling over traditional empirical based approaches are:

Level of detail: A model will obtain significantly more detailed information than experiments, enabling step increases in understanding of physical processes. It is not possible to observe or measure exactly what is going on inside a piece of equipment in experiments as there are few viable measurement techniques for moving, enclosed, dusty flow environments that quickly degrade any instruments. Their intrusion also commonly changes the flow attributes that are to be measured.

Cost: Traditional methods for designing equipment are experimental in nature. A design (or design change) requires some form of validation. This can be laboratory or pilot scale which is inherently expensive and time-consuming, and the final scale up is a risk. A simulation based approach offers the potential to be cheaper, faster and less risky. This is not a new concept; process simulation has been used for many years in Chemical Engineering to augment and/or replace pilot plants.

Paradigm shift – virtual testing. Simulation can be applied to concept equipment or processes without the need to even be able to build the devices, structures or processes and establish whether they are viable and then to optimize them. The successful concepts can then be designed from a mechanical and structural perspective. This means that the process engineering can dominate decision making instead of mechanical/structural considerations about whether a machine can be built or not. In a typical experimentally driven process, only devices that have been fabricated can be tested. This means that a many decisions and significant investments have been made before any real consideration is given to process efficiency. The use of simulation as the primary design tool promotes a fundamental change in thinking about how to design and optimize engineering processes.

3. Logistics Applications

SO are part of advanced operations management and decision-making in the logistics, transport and related service industries. The techniques have been applied successfully in many cases and particularly in certain niches (such as airline operations, e.g. see Clausen et al. 2010). They nevertheless remain underutilised by industry. The common perspective (Lawler et al. 1993) is that there are three levels of planning: strategic, tactical and operational has a clear interpretation in the case of transport and logistics. A fourth relevant area pervades these three temporally-distinguished levels, demand forecasting.

In logistics strategic planning, a common need is projecting future demand and then determining the necessary human and capital resources. SO can be used to appraise investment options and future performance of service networks (e.g. freight service network design problems, see Wieberneit 2008). Procurement, construction and/or commissioning of logistics resources typically have long lead times, so this planning horizon is typically more than 1 year. Tactical planning often deals with the equipment and people currently available, and seeks to satisfy demand at minimum cost and/or maximum profit. The time horizon is normally weeks or months, and the tactical plan can be produced and then updated as execution approaches. During operations, optimisation is primarily a tool to deal with updated demands and/or disruptions that affect delivery.

Cloud computing has the potential to assist in overcoming four practical impediments to adoption of logistics optimisation and simulation.

Problem speciality: The size and nature of the relevant literature demonstrates that each real-world logistics SO demands the skilled formulation of a problem. This specialization has made one-size-fits-all logistics planning and scheduling tools rare. In order solve the problems with acceptable levels of optimality and compute time, months or years of algorithm development can be required. This is despite ongoing improvement in general purpose tools such as integer programming solvers and discrete-event simulation platforms.

Computing requirements: Logistics planning and scheduling is computationally demanding (most real-world problems are NP-hard). Enterprise computing environments are not necessarily geared to support these memory and CPU intensive tasks, which can be intermittent yet require high-bandwidth connectivity with data sources and users.

Trust, data sharing and coordination: The opportunities for logistics SO can be inter-organisational. Competitive tensions between supply chain participants, as well as legislation and regulation to combat anti-competitive behaviour, can make logistics this difficult to implement. Simply coordinating planning activity across multiple parties can be a formidable challenge.

Demands on the enterprise: The life-cycle of logistics SO make strong demands on enterprises. In-house champions must understand the potential and identify opportunities. The enterprise has to find and engage advisors and suppliers who are trustworthy and competent. In-house IT expertise needs to understand and actively support "unfamiliar" initiatives, and management needs to overcome crises of confidence relating to the financial rewards, the organisation's ability to adopt, and external parties' ability to deliver.

4. Service Delivery

In considering how SO should be delivered to customers, we observe that decision-making that can benefit from these have typical characteristics:

- Complex problems requiring users with deep knowledge of the system under investigation.
- A large quantity of input data that can be complex in nature is required. Similarly, large amounts of output data are often produced.
- Compute intensive, requiring a powerful CPU, large memory and storage.
- Repeated runs, with changes in inputs, are often required.

The delivery mechanisms are normally consulting and software as a product.

In consulting, a person uses simulation tools to investigate a problem and propose a solution, normally in the form of a report and output data. While this addresses a particular problem, it does not enable the end user to do further investigation or revisit the issue as circumstances change, unless they re-engage the consultant. Often the consultant has created or enhanced a model capable of dealing with multiple instances of a problem.

If the consultant has specialist expertise not available in-house or proprietary software then this can be a good approach. But on a per-hour/per-unit basis this is typically the most expensive way to obtain engineering services. If the usage volumes become large, then the cost can become prohibitive and the advantages of other approaches become larger. Typically a consultant will be used if in-house capability cannot reasonably be established, or the service is not needed often enough to justify the expense of maintaining one. For end users, the consulting model represents an ongoing cost as the business changes, and the potential loss of control.

In software-as-a-product, end-user organizations procure software and have in-house or contracted staff apply it to the problem. This requires skilled and well-trained staff and also requires compute capacity with support. A prime potential advantage of using software in-house is that a user has much more control over the provision of the engineering service, and can obtain higher volumes of the engineering service per unit of cost. A key risk is quality control. Internal services are typically exposed to less external scrutiny, so if internal customers lack sophistication then they can be provided with sub-optimal service outcomes. The magnitude of this risk is heavily influenced by the quality of the senior in-house engineering staff and by the level of management experience.

When software is commercially available there is no automatic competitive advantage for an organization, since all competitors are also able to procure the same software. Competitive advantage can only be created by better and more sophisticated use to create business value. By contrast, leading-edge modeling capability is generally held in research organizations and is not easily available to third parties, which restricts the level experience of modeling services that can be established in-house unless a sizeable research team can be supported.

The hardware for large scale SO (typically now requiring highly parallel processing to get results in a reasonable time) is specialized and expensive. Even for more moderate requirements, such as those presented by transport schedule optimizers or smaller-scale fluid simulations, a high level of CPU load is needed in bursts between long periods of inactivity. The computers can be under-utilized yet never big enough! The costs associated with supporting such hardware including networking, data backup and recovery, archiving, maintenance and management of the facility can also be considerable.

Done well, using SO software in-house can be a major driver of business innovation. Done poorly, it can be a waste of resources and management energy. Another disadvantage of the consulting and software-as-a-product models is that, for consultants and software vendors, the accessible market can be limited and expensive to reach (marketing, sales and support).

The Application Service Provider (ASP) or Software as a Service (SaaS) model provides the ability for the end-user to access software without having to buy it or maintain the environment. However, this mainly addresses of the software procurement and hardware cost concerns. It does not address the other challenges. Training is still required, the system must be configured and fed with data, and the cost of reaching a limited market with software is not about distribution but rather about awareness and persuading customers to do something different and use their software.

CSIRO has been experimenting with web-based approaches for service delivery to try to meet these challenges. For around a decade it has considered how to provide engineering services in the area of grinding in tumbling mills. Multiple generations of Java/JavaScript web service called webGF-mill™ (Morton and Dunstall, 2004; webGF 2011) have been developed to enable potential users to model the flow of particles in their mills and to commission simulations. The first generation was built to operate on the client side, but this was found to have significant shortcomings in terms of data retention and continuity. The second generation was more java dominated with significant functionality held at the server end. This performed well in situations where the network connectivity was good, but since many potential customers are in remote areas where network connectivity and bandwidth are poor, this leads to very poor interactivity. This is one of the best ways of ensuring a poor customer experience. Automating the simulation part of the process for large scale engineering simulations also presents challenges with issues of software security and variability of client server configurations and operating systems if these are performed client side or data management and verification of input data if performed server side. These types of SaaS do not operate well in a traditional client-server structure regardless of whether the main work functions are hosted on the client or on the server. The third way is to host the service in a place with significant resources and support, local enough to have good network connectivity and bandwidth.

5. The Cloud – the Next Step in the Evolution of Service Delivery

Based on the investment in cloud services from organizations such as Microsoft, Amazon and Google, for general purposes, it could be argued that the natural evolution of services for engineering and logistics is in the cloud. The National Institute for Standards and Technology defines "Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction", (Mell and Grance, 2009). By way of this definition and the foregoing discussion, we propose that the essential points of difference between cloud computing and the consulting, software-ownership and ASP/SaaS models are: scalability, training and validation, data pooling and warehousing, configuration and data standards, reaching the market and enabling inter-organizational platforms.

5.1 Scalability

One of the key advantages of the Cloud is scale. The application is not restricted to end user hardware or hardware belonging to an ASP/SaaS provider. There is virtually unlimited capacity in terms of processors and memory. For SO software developers this offers the ability to tackle larger problem sizes and achieve higher solution speeds. Opposing this advantage is that parallelization of many methods is not straightforward. Constraints link inter-related variables making problems difficult to decompose into sub-problems. When problems are relaxed and decomposed to their maximum extent, speed-up using current state-of-the-art methods is sub-linear (Ernst et al. 2011). Nevertheless, massive scalability potential remains in terms of being able to solve many different problem instances in parallel.

5.2 Training and Validation

The definition of Cloud Computing includes 'services', which should necessarily include training. In keeping with the objective that resources are provisioned with minimal management effort, this implies computer-based training and validation as part of the service offer, or provided by a third party. Users expect software to be easy to use, and this drives demand (or creates a gap) in the market. From the supplier's perspective, the short term could be challenging due to the need to improve software while making training and validation accessible and automated. As elements are automated, support costs will tend to decrease and the perceived value of the software will increase.

5.3 Data Standards and Data Pooling

Cloud-based solutions demand appropriate ontology's and data standards. The upfront effort in this is useful for enabling Cloud-based solutions and a multi-organizational data pool. This has occurred in the wine industry, for example, where harvest-plan.com have adopted UNSPSC standards (http://www.unspsc.org/) and use data gathered over time to refine statistical models of grape maturation (improving the service offered).

5.4 Reaching the Market

The cost of reaching the end user with software is no longer a question of distribution. Even in the conventional ownership model, the transactional cost to buy and download software is minimal. Substantial costs are in communication (marketing) and persuasion (sales). Cloud solutions address some of these challenges. Users can find a software provider using a search engine or repository (providers have every incentive to make this so). Making software available to users in the Cloud facilitates a try-it-for-yourself model where different solutions to the same problem are available and able to be compared through reviews and trials.

Innovation is driven largely by the need to retain existing customers and find new ones. By its nature SO software requires expertise and training, which takes time and money to acquire (making users reluctant to switch). This enables conventional SO providers to spend less time thinking about existing customers and spend more time on new ones. Thus the users with the most experience and valuable opinions are listened to less than new customers, who know very little about using the software. It is better to spend money on sales and marketing than innovation! Putting software, side-by-side, ready-to-use without restriction with computerized training and validation and/or other services to help new users will inevitably bring performance and quality of the software to the top of the agenda for end users, and enable software providers to see how well they fare compared to the rest of the market.

The Cloud should not create more difficulties in establishing interoperability standards between competing SO software offerings. As in aviation (IATA, 2010) for example, we expect that user-community pressure will cause standards to emerge: so that a SO problem can be posed to different systems without modification. For suppliers of software there may be short term pain, as barriers to entry/switch are removed, but in the long term the key differentiator will be the capabilities and quality of the core software and the user experience.

5.5 Inter-Organizational Collaboration

Sharing information and participating in decision-making processes is a requirement and significant challenge for enterprises in supply networks. This is particularly true where multiple parties access critical and centralized assets such as ports, rail systems and processing centers. Competitive tensions and imbalances in organizational size and power give rise to issues related to data custodianship, hosting computation services, participation in decision-making processes and information sharing between participants. With secure multi-party computation (SMPC), the Cloud offers solutions to some of collaborative supply networks' other key computing-related issues. Sugar beet purchasing and processing in Denmark uses an SMPC system to protect growers' identity and auction parameters (Bogetoft et al., 2009).

6. Conclusions

SO as a technology offers considerable improvements, cost savings and environmental benefits for engineering services and logistics. Simulation, applied to industrial processes and equipment design reduces the cost of process design and creates and more efficient operation. Optimization, applied to transport and logistics, reduces cost and improves infrastructure utilization. Both of these have direct environment benefits. They are CPU intensive and require/create large amounts of data. They are suited to a Cloud computing solution that offers cost effective, scalable capacity. However, these applications are inherently complex and require expertise and training to get the best result.

Significant potential benefits of cloud computing for SO users would be the ability to get started quickly and to pose the same problem to different systems with reduced overhead. The potential for SO in the cloud will lead to increased end-user expectations and pressure on solution-suppliers to innovate. This will result in higher quality software, interoperability and reduced costs for both the end user and supplier. Cloud approaches also offer ways to diminish the influence of known impediments to the successful adoption, including difficulties with establishing data sources and overcoming inter-organizational distrust and confidence.

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