

Calculation Management[™]

Reducing Risk and Increasing Productivity
for Engineering-based Enterprises

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Summary: The case for Calculation Management™ in engineering enterprises



In failing to manage calculations, enterprises risk needless redesign and disastrous errors, meanwhile squandering intellectual capital.

Applied math calculations are the backbone of engineering—computing critical product parameters, analyzing test data, and predicting product performance. When Ben Rich of the legendary Lockheed Skunk Works recalled his early days there as a thermodynamicist, he said, “We were the analytical experts, the elite of the plant, who decreed sizes and shapes and told the draftsmen what to draw.”

Virtually every design decision is indeed informed by numerous calculations during each step of product development. Yet these calculations are not managed, per se. Product data management (PDM) and product life-cycle management (PLM) systems keep track of the results of calculations, but not of the full picture, which includes underlying assumptions.

Calculations in the engineering-based enterprise today are performed by hand, on calculators and spreadsheets, by writing programs, or using mathematical software; and they are scattered on desks, personal hard drives, document management systems, and file cabinets. In failing to manage calculations (through technology standardization, centralized storage, and global availability, for starters), enterprises risk needless redesign and disastrous errors, meanwhile squandering intellectual capital. Calculation management is itself a mission-critical business process, complementary to PDM and knowledge management.

Happily, it is neither particularly difficult nor expensive to begin managing calculations as a business process, so engineering-based enterprises have an opportunity to gain a significant return on their investment.

Calculation Matters: the Tay Bridge Collapse

The collapse of the Tay Bridge in a howling gale on December 28, 1879, less than two years after it was completed, is one of the most famous bridge collapses. Its designer, Thomas Bouch, was knighted when it was completed, but the glory was fleeting. A Court of Inquiry held him responsible for the collapse by using an inadequate wind loading assumption of 10 lbsf/sq ft.

Source: Tom Martin's Tay Bridge disaster page [<http://www.tts1.demon.co.uk/tay.html>]

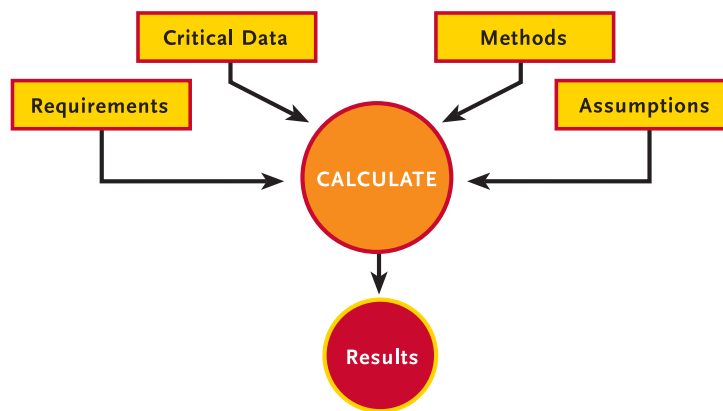
Calculation: Task or business process?

Enterprises support engineering calculations today on the level of task automation. Individual engineers typically choose their own tools ranging from spiral notebooks and calculators to math software based on personal preference, well under the radar of their IT organizations. This is certainly a path of least resistance: engineers keep their artistic freedom, and IT doesn't have to worry about them. So why change? Because calculation is a critical engineering process, and once companies begin to treat it that way, they stand to gain substantially greater benefits from their investments in calculation tools.

Calculation is a critical engineering process

The ABET defines design engineering as “the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective.”

Mathematics and analysis follow an iterative decision-making process, in accordance with the schematic below:



Individual calculations are concoctions of raw data, practical know-how, mathematical laws, and scientific principles that answer the mundane but vital questions, such as “How thick will this wall need to be to handle the required load?” The calculation process—advancing over the course of a project—is fundamentally what elevates engineering from trial-and-error and guesswork.

Imagine a flow-chart of the engineering process for a large project. It would be enormous, with loops and branches among sub-projects. The decision stream would have numerous tributaries, including the flow of calculations. Indeed, it is safe to say that the history of the calculation process—inputs, assumptions, methods and results—is among the most important records of an engineering project. Any unusual successes or failures are likely to be reflected conclusively within it.

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Calculation management is largely a matter of applying sound principles and technologies from the realms of information management and old-fashioned good housekeeping to the current calculation clutter.

Process improvement trumps task automation

It is common sense and well-known in the business world that automating a business process offers a much higher return on the technology investment than automating discrete tasks. In the late-1980s, the consulting firm Nolan, Norton & Co. put some numbers on the phenomenon, citing modest (10 to 20 percent) ROI for task automation and impressive returns of up to 300 percent for business process automation. Today's leading expert on IT investment as it relates to worker productivity is Erik Brynjolfsson, a professor at the Center for eBusiness at the Massachusetts Institute of Technology's Sloan School of Management. He has spent years studying the business process changes, small and large, that are precipitated by new technologies, and which he believes account for the really impressive productivity gains.

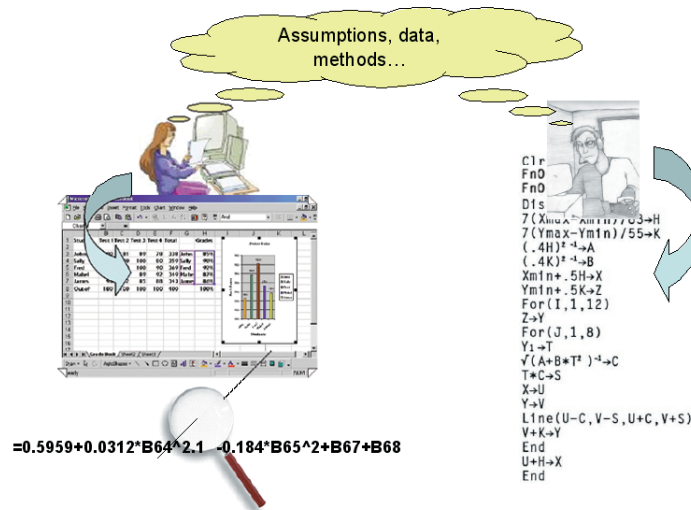
Brynjolfsson's study of 1,167 large companies in 41 industries concluded that productivity growth arises from the combination of new technologies and new business processes. Addressing an eBusiness conference in Cambridge, Massachusetts in 2002, Brynjolfsson said companies' productivity and market value were not as closely linked with IT spending as with "how they used technology. It was what they were doing with it. And it was their corporate culture, their attitudes towards a whole set of information-related decisions."

Calculation management

Calculation management is not rocket science. It is largely a matter of applying sound principles and technologies from the realms of information management and old-fashioned good housekeeping to the current calculation clutter.

Life with unmanaged calculations

Consider a group of engineers brainstorming the redesign of an axle in a conference room. After the meeting breaks up, Fred and Mary work up calculations on two key components.



Mary creates a spreadsheet to forecast the type and number of bearings to be used, while Fred writes a program to calculate stresses on a modified u-joint for off-road use. In the picture above, we see a formula from Mary's spreadsheet and some of Fred's code. These are essentially the only enterprise records of that brainstorming session. The whiteboard was erased. Fred's notes were on the legal pad he took to the meeting, and Mary's notes are in a spiral notebook on her desk.

As the axle design proceeds, the answers produced by the spreadsheet and the program form the basis for ensuing calculations.

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Controlled experiments show that 40% to 80% of spreadsheets contain errors at their inception.

Mary's bearings spreadsheet is eventually adapted for calculations of other assemblies. A random audit later uncovers errors in 5 percent of the cells. The company has been overspending on bearings as a result, but at least the overdesign poses no danger to customers. Meanwhile, the new u-joint has failed repeatedly when driven over logs. A recall may be necessary, and a government investigator wants to know what assumptions were used for flexing of the axle on uneven terrain. Fred's program is still in the project document management system, but Fred himself has trouble reverse-engineering his code.

Scenarios like this are unnervingly common in engineering-based organizations, with varying degrees of impact.

The Trouble with Spreadsheets

Spreadsheet expert Raymond Panko of the University of Hawaii has written that, "Every study that has attempted to measure errors, without exception, has found them at rates that would be unacceptable in any organization."

Rick Butler, an auditor who writes and speaks widely on spreadsheets, asserts that controlled experiments show that 40% to 80% of spreadsheets contain errors at their inception. Spreadsheet developers miss more than 80% of their own errors, and outside testers miss over 50% of design logic and 34% of application errors.

In 1987, Davies and Ikin inspected 19 spreadsheets that were in use and deemed correct from 10 developers in 10 different firms. Four contained serious quantitative errors, and three-quarters of them included quantitative or qualitative errors. One error involved a \$7 million funds transfer between divisions. In another case, inconsistent currency conversion numbers showed up in different parts of the spreadsheet.

Sources: Raymond R. Panko, "What We Know About Spreadsheet Errors," Summer 2000 from the Spreadsheet Research web site.; Rick Butler, "The Subversive Spreadsheet." European Spreadsheet Risks Interest Group

Unmanaged calculations contribute to the following enterprise-level problems:

- *Risk*: Computer programs are difficult to reverse-engineer, so the probability that they will be verified formally or informally declines almost to zero. That means errors are likely to show up downstream, or worst case, in the final product.
- *Re-work and wasted time*: Poorly documented calculations are dangerous to reuse. This means the same problems get solved over and over again. And schedules slip.
- *Lost knowledge*: If the lessons Fred and Mary learned were exposed in their work, they could be refined and used for the benefit of many projects.
- *Cold audit trails*: In an emergency, an engineering team that cannot retrace its steps quickly risks adding public relations insult to existing injury.

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Basic principles of calculation management

Principle 1: Managing calculations includes managing underlying assumptions

While many tools, such as spreadsheets and programs, can successfully automate calculations, the assumptions and data underlying those calculations are effectively obscured by most of them. And without the information behind the answers in some readable and manageable form, how much is a company willing to risk reusing those answers in the future?

Assumptions don't record themselves, but companies can provide a calculating environment (through technology and training) that is conducive to thorough documentation.

Calculation Matters: the Chaparral 2E

As reported in the Competition Press on October 8, 1966, "The spoiler on the new Chaparral 2E more than lived up to its name in [the] second round of the Can Am series." Twice, on different cars, rods that supported the spoiler broke and ultimately blew out a tire each. The spoiler was brand new and very nifty, allowing the driver to adjust its angle to increase drag for braking or cornering. The car's famous designer, Jim Hall, ascribed the failure to fatigue, and a mistaken assumption in his original design. He calculated the main force acting on the link using a maximum lateral acceleration of 1G.

*Source: Engineering Case Studies (ECL 79), Carleton University, Ottawa, Canada.
[<http://www.civeng.carleton.ca/ECL/reports/ECL79/ecl79d.html>]*

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Your calculation management tools should offer a user-friendly display, produce hard copy that is easy to work with, and interface neatly with relevant software.

Principle 2: Liberate calculations from particular media and applications

Math is a particularly challenging datatype. Often when equations are represented most accessibly (as in printed materials and handwritten notes), they don't work; they're just pictures. Meanwhile, working formulas in most applications are forbidding to the eye.

Here's an example of an engineering equation in standard math notation, as rendered by Mathcad:

the equivalent RMS noise current is approximately

$$I_n := \sqrt{\left(\frac{4 \cdot k \cdot T}{R_p} + \frac{\epsilon_n^2}{R_p^2} \right) \Delta f_v + \frac{4}{3} \cdot \pi^2 \cdot C_S^2 \cdot \epsilon_n^2 \cdot \Delta f_v^3}$$

Here's how the same equation would appear in a spreadsheet:

	A
1	=SQRT(0.00000000000324645*B1+1002.4356*B1^3)
2	
3	

We all know the frustration of entering the same information into an array of databases or other sprawling applications that are intended to save labor. Your calculation management tools should offer a user-friendly display, produce hard copy that is easy to work with, and interface neatly with relevant software.

Principle 3: Establish rules and procedures for calculation management

Successful calculation management strategies are a logical and natural outgrowth of current practices. These systems should improve the enterprise's control over valuable intellectual capital and make it easier for engineers to do their jobs by:

- *Promoting reuse* and creating libraries of in-house standards and methods.
- *Centralizing key parameters.* Certain variables, such as material properties, find their way into most calculations. Keeping these key parameters under centralized management ensures that all calculations use the most reliable values. Moreover, the impact of changing those numbers can be assessed and minimized.
- *Making calculations and standards available online.* The Internet is the eye-level shelf for the information consumer, and remote access is essential for many engineering firms whose employees are frequently out in the field.

Benefits of managing the calculation process with Mathcad

Several Mathsoft customers have already profited from building processes around calculation. One inherent benefit of Mathcad is that engineers like using it, whereas they tend to view most “knowledge management” technologies as overhead. The following examples show how several leading engineering-based companies succeeded with independent calculation management efforts using Mathcad.

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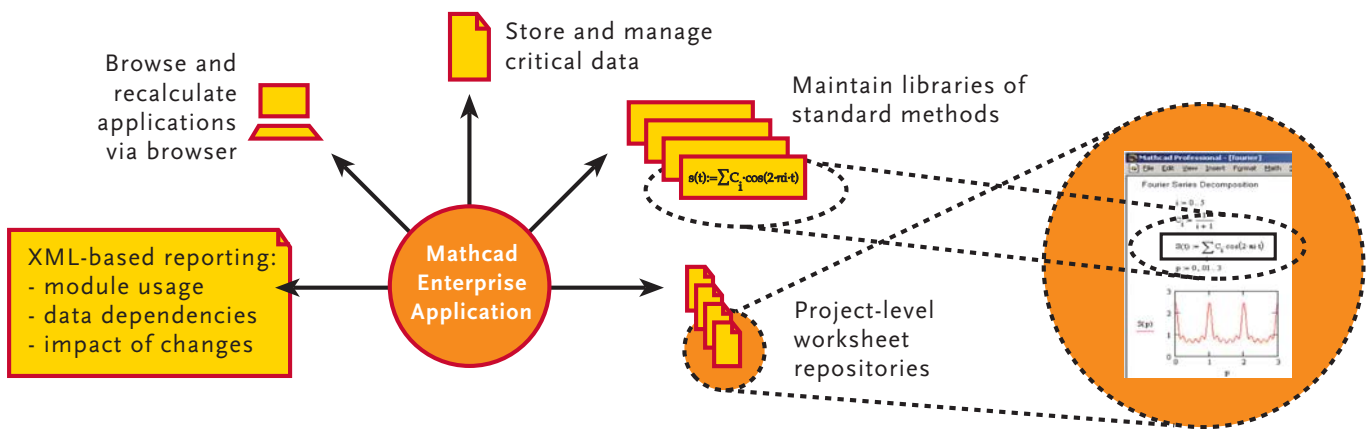
- *Centralized calculation repository* – An aerospace contractor identified over 2,000 critical design calculations needed to produce large aircraft fuel tanks. These calculations are now housed on a central server, and used routinely. The requirement for engineers to read, understand and customize these applications, and then disseminate complete analyses, made Mathcad the only choice for this application.
- *Improved calculation integrity and easier validation/review* – A major multinational engineering firm wanted to standardize their methods for calculating parameters of bolted girder joints and other structural elements for large building projects. Because these calculations are performed daily by hundreds of entry-level engineers, requiring downstream validation and review, this firm chose to create a central repository in the form of Mathcad worksheets. The firm then built a web service with custom Visual Basic forms that also allows engineers to use the worksheets remotely. Each time a worksheet is used, the calculated results and validity checks on the parameters are fed back to the engineer’s browser, and the worksheet itself remains as the “audit trail“ for the calculation in the usual very readable Mathcad format.
- *Templates enforce design standards* – A major OEM of auto parts has developed Mathcad-based templates containing large numbers of functions and data sets useful in their design engineering activities. These templates ensure that all the engineering staff use the same functions and data sets, and the correct information in doing their calculations. At this site, parts of Mathcad worksheets are often found in PowerPoint presentations, memos, emails, and other forms of communication.
- *More accurate, more readable deliverables* – A major aerospace company used to deliver engineering analyses to their US Government clients in the form of Excel spreadsheets. Government engineers spent significant time checking each one, and invariably found at least one error in each. This group has transitioned to using Mathcad exclusively for these deliverables, sharply decreasing validation time by the Government and reducing the error rate almost to zero.

Mathcad Enterprise: designed especially for Calculation Management™

For the vast majority of calculations engineers perform, Mathsoft's flagship product Mathcad® is the right application to use, both for personal productivity and enterprise-level management of a valuable asset.

Millions of engineers already use Mathcad in more than 90 percent of the Fortune 1000. Calculation management with Mathsoft begins with standardizing on Mathcad, with its undisputed strengths in calculation and user-friendliness at the individual level. From there, Mathcad Enterprise provides central calculation storage and management, scalability, interfaces to systems such as Microsoft Office and SharePoint™, and training in best practices for deploying Calculation Management at the group, departmental, and enterprise levels.

The illustration below shows the building blocks of Mathcad Enterprise.



The following features can be based on SharePoint repositories supported directly by Mathcad Enterprise, or integrated with other document management, PDM, or PLM systems:

- Libraries of reusable methods. Mathcad's readability ensures that calculations are accessible to any engineer. With locks and password protection, whole sections of analysis can be "certified error-free" or designated as restricted access, for instance.
- Centralized access to key parameters. Make sure your engineers are all using the same values for critical variables that show up often in your calculation work.

- Web deployment of designs and applications. Mathcad worksheets can already be deployed globally to other Mathcad users, and via Adobe PDF® or HTML to anyone with a PC or a web browser. With the Mathcad Application Server (available in the summer of 2003), Mathcad worksheets can be viewed and recalculated from any web browser, turning them into rich web applications without any programming.
- Electronic Handbooks. Mathcad allows authoring of indexed, hyperlinked “ebooks,” which some companies find useful for compiling common calculations, methods and data.

Conclusion

Mathsoft takes the broadest view in supporting engineers, beginning with calculation tasks and continuing through calculation management at the group, department and enterprise levels.

Calculation management is open territory for business process automation in engineering. Mathsoft has created a medium for expressing, performing, and managing engineering calculations that opens up a range of high-value applications to your organization.

More about Mathcad®

Mathcad is based on a patented “live document interface” in which users can include their assumptions (or comments or lines of reasoning) and type their formulas in textbook-style math notation directly into Mathcad’s exceptionally flexible worksheets. Mathcad then automatically calculates and displays results directly in the document. We have learned over the years that the way Mathcad encourages engineers to document their calculations has created tremendous value for customers, and driven the sales of more than 2.5 million licenses for Mathcad products since 1986. Now, in 2003, users can still load any vintage Mathcad file into Mathcad version 11.

ⁱ Accreditation Board for Engineering and Technology, Inc.

ⁱⁱ Based on “Managing Personal Computers in the Large Organization,” Nolan, Norton & Co., 1987.

ⁱⁱⁱ Rick Whiting, “Building Organizational Capital,” *InformationWeek*, April 19, 2002.

www.mathsoft.com

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