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eBook: How to Choose the Optimal Math Software for Engineers

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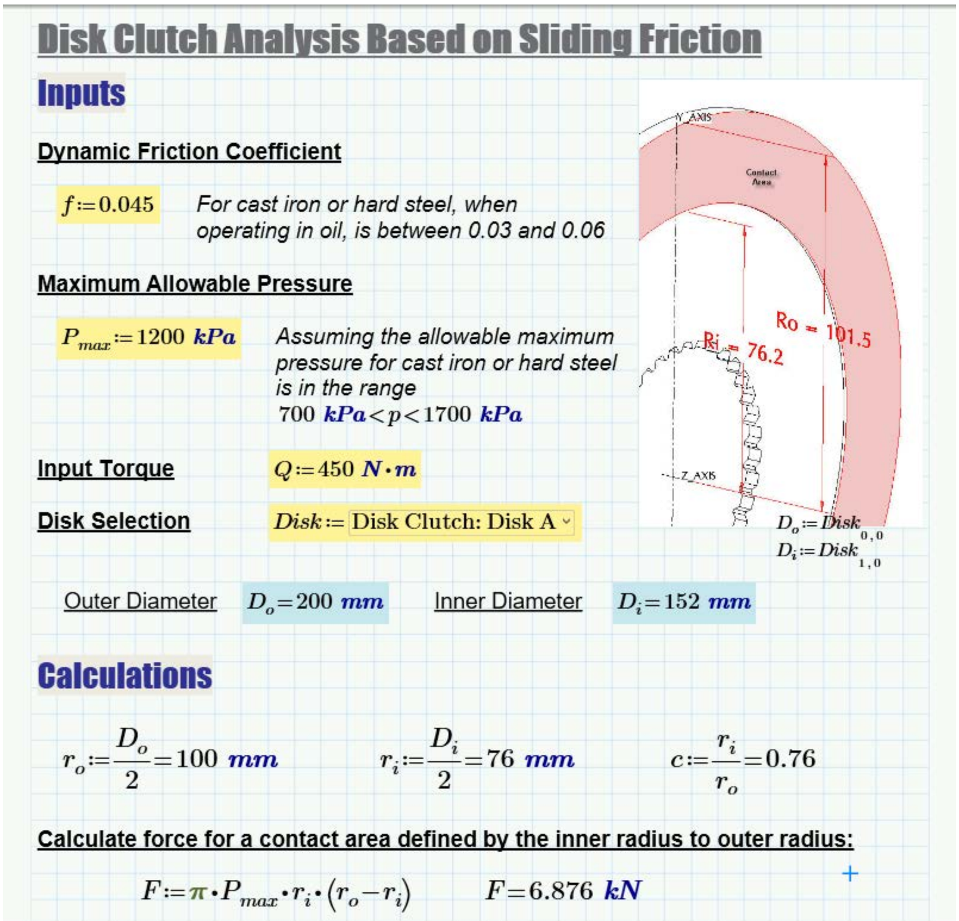
THE IMPORTANCE OF MATH SOFTWARE IN ENGINEERING

Engineering mathematics software has become a cornerstone of the profession. During early development, these tools enable engineers to perform back-of-the-napkin calculations as fast as they can write down fundamental equations. These tools also have various uses throughout the development process. Perhaps most notable is the ability of math software to produce formal engineering documents.

Spreadsheets and word processors still occupy a large portion of the engineering calculation and documentation realm. However, their abilities are not optimized for these tasks. For instance, it is clunky to use spreadsheets for engineering calculations, as the equations are hidden (within a formula bar) and further obfuscated with awkward function names and syntax. This makes it harder to check these calculations.

Bringing spreadsheet computations into word processors requires the use of copy-paste functions or the linking of files. The former is easy to perform, but ensures that the word document will not automatically update as calculations change. The latter can be complex, and can slow down the operations within both documents.



Disk Clutch Analysis Based on Sliding Friction

Inputs

Dynamic Friction Coefficient

$f := 0.045$ For cast iron or hard steel, when operating in oil, is between 0.03 and 0.06

Maximum Allowable Pressure

$P_{max} := 1200\ kPa$ Assuming the allowable maximum pressure for cast iron or hard steel is in the range $700\ kPa < p < 1700\ kPa$

Input Torque $Q := 450\ N \cdot m$

Disk Selection $Disk :=$ Disk Clutch: Disk A

$D_o := Disk_{0,0}$

$D_i := Disk_{1,0}$

Outer Diameter $D_o = 200\ mm$ Inner Diameter $D_i = 152\ mm$

Calculations

$r_o := \frac{D_o}{2} = 100\ mm$ $r_i := \frac{D_i}{2} = 76\ mm$ $c := \frac{r_i}{r_o} = 0.76$

Calculate force for a contact area defined by the inner radius to outer radius:

$F := \pi \cdot P_{max} \cdot r_i \cdot (r_o - r_i)$ $F = 6.876\ kN$

Figure 1. Engineering documents produced using mathematics software. (Image courtesy of PTC.)

There are important benefits when math software uses the same notations that engineers write on paper. Especially if the software has a strong math engine that can interpret mathematical expressions, compute numeric and symbolic expressions and maintain units within complex problems. When these computations can be processed and computed within the same document as text, plots and images, it simplifies the engineering documentation process.

But how do engineers differentiate between the math software available on the market? How can they decide which one will better fit their workflows and internal systems? This eBook examines business decision processes, and the variables engineers need to consider to focus specifically on math software. The goal is to ensure all organizations choose math software that meets their engineering goals. It also covers how to create a decision matrix and includes sample worksheets to help engineers make informed choices.

Thank you for reading.

Sincerely,
Shawn Wasserman
Sr. Editor, engineering.com

HOW BUSINESSES MAKE ENGINEERING SOFTWARE DECISIONS

Generally speaking, business decisions should be broken down into five steps:

1. **Identify Goals**
   - Speak to all stakeholders and assess what problem(s) needs to be solved.
   - Obtaining a hammer is not a goal, it is a potential solution to achieving a goal.
2. **Gather Information**
   - Identify potential biases.
   - Research potential solutions that meet the goals.
   - Develop a short list of options.
3. **Identify the Optimal Solution**
   - Determine variables that can assess each potential solution based on the goals.
   - Evaluate the information to determine optimal solution(s) for the given problem.
4. **Make a Final Decision**
   - Based on a short list of optimal solutions, pick one.
5. **Assess the Results of the Decision**
   - Determine if the solution was a success over the short and long term.
   - Determine what could optimize the selection process in the future.

For a more in-depth discussion of each of these steps, read the section *All the Steps of a Formal Decision-Making Process*, in the Appendix.

Figure 2. Obtaining a hammer is not a goal. It is a potential solution to achieving a goal. Assess if it is the best solution.

Perhaps one of the most powerful tools to help businesses make decisions is to use a decision matrix. This is a great place to summarize all the findings (of steps one to three) in one place. It can also help eliminate bias from the selection process while helping to identify the optimal solution. For a more in-depth look into how to make decision matrices, read the section *How to Make Decision Matrices*, in the Appendix.

WHAT VARIABLES SHOULD ENGINEERS ASSESS WHEN PICKING MATH SOFTWARE?

Each organization will have different reasons for wanting math software. Therefore, the variables used to assess the software, and how those variables are weighted, will differ based on the goals they wish to achieve. However, there are some principal variables organizations can use to assess math software.

Once these variables are agreed upon, the organization will need to come up with questions, tests and other criteria to evaluate how the potential solutions perform in these areas. When coming up with these assessments, remember to keep the project goals in mind.

Here is a list of some principal variables, questions, tests and assessments that organizations can use to assess math software solutions:

EASE OF USE

- Does the software's standard user interface focus on recreating the feel of a whiteboard, a programming interface or something else?
- Is the software capable of creating engineering documents using a what you see is what you get (WYSIWYG) view?
- Does the software use natural math notation, or does it use named functions and programming syntax?
- Does the user interface use a ribbon, or are tools organized in other ways?
- Does the software suggest operations to perform next?
- Will the software notify users about errors in syntax, logic, format, etc.?
- How long will it take to train the team to use the software?
- How long did it take the testers to perform sample problems and tasks?

THE MATH ENGINE

- Are computations performed instantaneously, or when the software is instructed to?
- Are programming constructs and tools available, if needed, for advanced problems?
- Is it possible to create custom functions?
- What form of unit intelligence does the software have?
- Will units be carried forward and converted automatically?

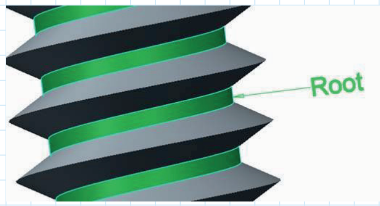
- Does the software include a symbolics calculation engine?
- Does the scope of the symbolics engine encompass everything needed to meet the goals (i.e., does it manipulate algebraic expressions, solve equations, understand matrices and perform symbolic transforms)?
- How does the software handle round-off error?
- Does the software successfully complete all the sample problems and tasks it is given?
- How long does it take the software to compute the sample problems and tasks?

DOCUMENTATION

- Can the software handle free layouts or does it have predefined structures?
- How is information consolidated?
- Is it possible to integrate the math, text, pictures, plots, diagrams and tables into a single document?
- Can the software make engineering documents in a format needed to meet the goals?
- Is scratch space available to perform test calculations and explorations?
- Does the software provide flexibility to control what content is displayed in the final document?
- Can templates be made to standardize documentation?

Surface Area of a Threaded Bolt for Electro-Plating

$$A_{surface}=\frac{2\,\pi\,(D-d)\cdot l}{p\cdot cos\left(\frac{\alpha_T}{2}\right)}$$



Nominal diameter — Pitch

No.	D_1 (mm)	D_2 (mm)	P_{coarse}	P_{fine}
0	1	0	0.25	0
1	1.2	0	0.25	0
2	0	1.4	0.3	0
3	1.6	0	0.35	0
4	2	1.8	0.4	0
5	2.5	0	0.45	0
6	3	0	0.5	0
7	0	3.5	0.6	0
8	4	0	0.7	0
9	5	0	0.8	0
10	6	0	1	0
11	0	7	1	0
12	8	0	1.25	1
13	10	0	1.5	1.25
14	12	0	1.75	1.5
15	0	14	2	1.5

Since some diameters are undefined in both columns, the max of both is calculated and used instead:

$i:=0\,..\,\text{length}(D_1)-1$

$D_{nom_i}:=\max\left(D_{1_i}, D_{2_i}\right)$

$D_{nom}=\begin{bmatrix}1\\1.2\\1.4\\1.6\\2\\2.5\\3\\3.5\\\vdots\end{bmatrix}mm$

Given:

$d:=0.86\ mm$ Thread depth

$l:=100\ mm$ Length of threaded part of bolt

$\alpha_T:=60\ deg$ Thread angle (60deg for ISO)

D_{nom}, P_{coarse} — Nominal diameter(m) and coarse thread pitch (unitless) values are used from table above.

Total surface area is calculated for each bolt combination:

$$SA(i):=\frac{2\,\pi\cdot\left(D_{nom_i}-d\right)\cdot l}{P_{coarse_i}\cdot\cos\left(\frac{\alpha_T}{2}\right)}$$

Figure 3: A standard template for an engineering document. (Image courtesy of PTC.)

INTEROPERABILITY

- Does the software interface with in-house and legacy systems?
- Does the software interface with industry standard applications and files, such as:
  - Excel
  - Word
  - Adobe PDF
  - CAD software
  - Text documents
  - Object linking and embedded (OLE) objects
- Does the software have read and write capabilities to current data systems and files?
- Does the software have API functionality to create interactions as needed?

SECURITY

- How does the software protect intellectual property when documents are shared?
- Can the software be subjected to hacking, exposure or other security risks?
- Can sections in a document be password protected?
- How does the software handle work-in-progress if there are system/ connection errors?

SUPPORT

- Do the software developers release updates based on user feedback?
- How easy is it to reach customer support?
- What is the scope of customer support? Does it include:
  - Tech support
  - Licensing support
  - Troubleshooting
  - Calculation errors
- Is there ample learning material available (like demos, tutorials, webinars, etc.)?
- Is the user community large, healthy and helpful?

DEPLOYMENT

- Is the software available on the cloud, or is it only available on workstations?
- Does the software require internet access?
- How are updates handled and deployed?

LICENSING

- How much will the software cost?
- Is the license perpetual or subscription based?
- Do users pay for updates and new releases, or are they rolled out automatically?
- Is it a software-as-a-service (SaaS) licensing model?
- Are both individual and network (shared) licenses available?

Though this is not an exhaustive list of variables and assessments, it is a great starting point. Choose any of the above variables and assessments that make sense with respect to the goals of the project and the needs of the organization.

Once all these variables and assessments are decided upon, start comparing the math software based on the gathered information. Then plug that into a decision matrix and see what options are optimal. From there it should be easier to make a final decision.

For instructions on how to fill in a decision matrix, read the section How to Make Decision Matrices, in the Appendix. To try this out with the variables mentioned above, fill in the decision matrix worksheet in Figure 6 in the Decision Matrix Worksheets section of the Appendix.

APPENDIX

ALL THE STEPS OF A FORMAL DECISION-MAKING PROCESS

The first step of any important business decision should be to identify goals. This might sound obvious, or even skippable. However, failing to identify the goals from the perspective of all stakeholders could result in decisions that are unsuitable.

The goal in this case should not be to purchase math software. No one wants a hammer and nails; what they want is a picture up on the wall. The hammer and nail are simply one solution to reach that goal. The same goal could be achieved using Velcro and adhesives. Alternatively, if the picture is unframed then both previous solutions are suboptimal compared to tape, thumb tacks or mounting putty.

In the case of math software, assess all the goals that need to be achieved using this tool. To do so requires speaking to all stakeholders. This includes the people that will use the software to produce documents, the people that use the documents and the customers that interact with the documents.

Ask questions such as:
- Are all goals aligned?
- Do any goals supersede another?
- What biases does each stakeholder have?

Once the final goals are decided, it is possible that many of the potential solutions can be eliminated at the very beginning of the process. If the goal is to streamline the engineering documentation process, then word processors and spreadsheets are unlikely to be the optimal tool (as discussed in the section The Importance of Math Software in Engineering). When these tools are selected, it is usually because they are ubiquitous—not because they are best for the job.

The next step is to gather information about the problem and potential solutions. Then, assess all the possible courses of action. This may sound simple, but it is often the longest step of the decision process. If it is possible to get access to demo versions of the software, this is the time to do so. Play around with the software and assess how it feels and whether it works the way it should for the problems at hand. Run a few test problems and daily tasks through the software to assess which ones perform the best. Determine which software will be easiest to learn and integrate into legacy systems.

A great way to start eliminating more options is to find all the must-haves for the project, and if a solution does not have that option, it can be safely eliminated at this step.

At this point, the potential solutions should be narrowed down to a short list. Each option on the list should be capable of achieving the goals. The challenge is to identify which solution is optimal for the given scenario. For each company, the optimal choice will differ.

To make the final decision, weigh the evidence carefully using tools such as:

- Decision matrices
- Pro-con lists
- Decision trees
- Voting
- Pareto analysis
- Cost-benefit analysis
- Customer preferences
- Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis
- Political, Economic, Social and Technical (PEST) analysis

Each of these assessments have their own benefits, weaknesses and biases—some may even feel superficial. However, the most helpful aspects of these tools are the ability to help teams come to a consensus by ensuring all stakeholders understand the assumptions and steps in the decision process. These tools help avoid circular conversations, shine a light on potential potholes (like extrapolation or sunk costs bias) and help the team convince management.

It is best to use more than one of these tools before making a final decision because it will help to ensure that all options are properly assessed. That being said, the decision matrix is one of the most powerful. It could serve as a locus to summarize all the information determined from the other assessments (more on that later).

Figure 4. A decision matrix assessing which type of screws to use for a project based on maintenance, security, stripping and supply. The numbers are arbitrary, but in this case, square screws would be the optimal solution.

		Maintenance score	Maintenance Wt. score	Security score	Security Wt. score	Stripping score	Stripping Wt. score	Supply score	Supply Wt. score	Total Wt.
	Weight	30%		30%		20%		20%		100%
Types of Screws to Use	Square	10	3	8	2.4	8	1.6	7	1.4	8.4
	Slotted	8	2.4	5	1.5	6	1.2	8	1.6	6.7
	Phillips	9	2.7	7	2.1	7	1.4	10	2	8.2
	Security Torx	6	1.8	10	3	10	2	6	1.2	8
	Spanner	5	1.5	9	2.7	5	1	5	1	6.2
	Allen	7	2.1	6	1.8	9	1.8	9	1.8	7.5

The final step in the decision-making process is to make a final decision. Remember to evaluate the decision over the long-term and short-term. This final step will help to assess the overall experience, how successful it was and what can be done better in the future.

HOW TO MAKE DECISION MATRICES

A decision matrix is a tool used to compare potential solutions against a handful of variables of various importance. It is best used once there is already a short list of options that can meet the intended goal. In Figure 5, the list of options would appear in cells A to F.

		Var 1 score	Var 1 Wt. score	Var 2 score	Var 2 Wt. score	Var 3 score	Var 3 Wt. score	Var 4 score	Var 4 Wt. score	Total Wt.
	Weight	20%		30%		30%		20%		100%
Potential Solutions	A	10	2	5	1.5	6	1.8	7	1.4	6.7
	B	9	1.8	10	3	5	1.5	6	1.2	6.5
	C	8	1.6	9	2.7	10	3	5	1	8.3
	D	7	1.4	8	2.4	9	2.7	10	2	8.5
	E	6	1.2	7	2.1	8	2.4	9	1.8	7.5
	F	5	1	6	1.8	7	2.1	8	1.6	5.5

Figure 5. A decision matrix assessing potential solutions A to F against variables 1 to 4.

The next step would be to determine the most important variables that the solutions should be assessed against. Too few variables may not assess the solutions against all useful criteria; however, too many variables will water down the importance of some of the more pressing criteria. The safe bet is to assess anywhere between four to twelve variables. If it is difficult to decide on variables to assess the solutions against, consider the examples in Figure 6 in the Decision Matrix Worksheets section of the Appendix and the section What Variables Should Engineers Assess When Picking Math Software? In the example of Figure 5, these variables would be listed along the top row where it notes “Var 1” to “Var 4”.

These variables now must be weighted based on their importance. Assess which variables have a bigger impact to reaching the goals of the project. Some of this will be subjective, but after the research step it should be an educated guess.

There are various methods to weight the variables. However, the most straightforward is to assign each variable a percentage based on how important it is to the whole project. In Figure 5, Var 2 and Var 3 have equal importance, but they are more important than Var 1 and Var 4. Additionally, Var 1 and Var 4 are of equal importance. Finally, all the assigned percentages add up to 100 percent.

Next, rank each potential solution based on each potential variable. The higher the score each solution achieves, the better it performed with respect to that variable. Be sure to be consistent with the rankings; in the case of Figure 5, each solution was ranked out of ten. These numbers appear in the purple columns.

The rankings are then multiplied by the weight percentage for each given variable. Those numbers are then placed in the white columns. In Figure 5, solution A received a 10 for Var 1. This score was then multiplied by 20 percent, the weighing value, to get a weighted score of 2. Meanwhile, solution E received a score of 8 for Var 3. That score was multiplied by 30 percent to get a weighted score of 2.4.

Finally, the weighted scores are added up in the green column. In Figure 5, Solution D received weighted scores of 1.4, 2.4, 2.7 and 2 for Var 1 to Var 4, respectively. These numbers add up to 8.5, the highest total score in the chart. As a result, the decision matrix suggests that Solution D is the optimal option. However, upon closer inspection, Solution C appears to have similar scores to Solution D. Therefore, it may be prudent to assess both options more closely before making a final decision.

Sample decision matrix worksheets for assessing four, eight, or twelve variables can be found in the *Decision Matrix Worksheets* section of the Appendix under Figure 7 to Figure 9.

DECISION MATRIX WORKSHEETS

Chart 1a		Ease of use Score	Ease of use Wt. score	Math engine Score	Math engine Wt. score	Documentation Score	Documentation Wt. score	Interoperability Score	Interoperability Wt. score	Chart 1a Total Wt.
	Weight	%		%		%		%		%
Math Software										

Chart 2a		Security Score	Security Wt. score	Support Score	Support Wt. score	Deployment Score	Deployment Wt. score	Licensing Score	Licensing Wt. score	Chart 2a Total Wt.	Chart 1a Total Wt. + Chart 2a Total Wt.
	Weight	%		%		%		%		%	100%
Math Software											

Figure 6. Chart 1a and Chart 2a are a sample decision matrix worksheet to assess math software against the eight variables mentioned in the section: What Variables Should Engineers Assess When Picking Math Software? The total weight of the eight variables should come to 100 percent.

		Score	Wt. score	Score	Wt. score	Score	Wt. score	Score	Wt. score	Chart Total Wt.
	Weight	%		%		%		%		100%
Solutions										

Figure 7. This is a sample decision matrix worksheet assessing four variables. The total weight of the four variables should come to 100 percent.

Chart 1b		Score	Wt. score	Score	Wt. score	Score	Wt. score	Score	Wt. score	Chart 1bTotal Wt.
	Weight	%		%		%		%		%
Solutions										

Chart 2b		Score	Wt. score	Score	Wt. score	Score	Wt. score	Score	Wt. score	Chart 2b Total Wt.	Chart 1b Total Wt. + Chart 2b Total Wt.
	Weight	%		%		%		%		%	100%
Solutions											

Figure 8. Chart 1b and Chart 2b are sample decision matrix worksheet assessing eight variables. The total weight of the eight variables should come to 100 percent.

Chart 1c		Score	Wt. score	Score	Wt. score	Score	Wt. score	Score	Wt. score	Chart 1c Total Wt.
	Weight	%		%		%		%		%
Solutions										

Chart 2c		Score	Wt. score	Score	Wt. score	Score	Wt. score	Score	Wt. score	Chart 2c Total Wt.	Chart 1c Total Wt. + Chart 2c Total Wt.
	Weight	%		%		%		%		%	%
Solutions											

Chart 3c		Score	Wt. score	Score	Wt. score	Score	Wt. score	Score	Wt. score	Chart 3c Total Wt.	Chart 1c Total Wt. + Chart 2c Total Wt. + Chart 3c Total Wt.
	Weight	%		%		%		%		%	100%
Solutions											

Figure 9. Charts 1c to 3c are a sample decision matrix worksheet assessing twelve variables. The total weight of the twelve variables should come to 100 percent.

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