ENG 3PX3 - Engineering Economics

McMaster University

# Technical Analysis in Engineering Design

# Intended Learning Outcomes

→**Today:**

- Present an example of technical analysis to illustrate what it looks like.
- Tip: Don’t get lost in the weeds!  We’ll focus here on the *results* of the analysis and *what to do with it* but won’t spend time to *do* the analysis (this can take a long time depending on how detailed you want to be! Don't beat yourself up if it feels like you're going slow or are bad at this; doing engineering analysis takes practice and experience!)

# Intended Learning Outcomes (ILOs)

→**Main ILO**

- Can do an engineering technical analysis specific to your discipline (e.g., Mech Eng, Software Eng, etc.) in the context of an engineering economic analysis as an aid for engineering design.

→**Enabling ILOs**

- Can ID decision variables vs. performance parameters
- Can describe engineering technical analysis, recognize it in application, and explain how it’s used in engineering economic analysis
- Understand the requirements for the technical analysis you’ll do in 3PX

# Technical Analysis - Definitions

# What is Engineering Technical Analysis?

→**Using science (e.g., equations) to determine how variables are related in order to draw conclusions in an engineering-relevant context (e.g., design, engineering economic analysis, etc.)**

- The science should be at or above the level of things you've learned in undergrad engineering courses
  - (if you could do it without the course info it probably isn't engineering).

# What is Engineering Technical Analysis?

→**Note:**

- Engineering licensing isn't discipline specific (you'll get a "P.Eng.", not a "P.Eng. Civil" or "P.Eng. Software")
  - It's up to you on a task-by-task basis to know whether you can take it on, and you'll be held to the standard of someone who normally **would** do that work!
  - For the 3PX project, stick to analysis covered by content your courses covered and make assumptions about everything else you need to get that analysis done

# What is Engineering Design?

→1. **Making decisions**

- on the basis of engineering principles (applied math, physics, chemistry, or related applied sciences at the level at or beyond what you learn in undergrad engineering programs)

→2. **to create plans**

- for someone (probably someone besides you) to create or modify something

→3. **that is for the benefit of humans**

- (e.g., concerns protecting public welfare, environment, economic interests, etc.).

# What is Engineering Design?

→**Notice that:**

- you need to be applying math & science for it to be engineering,
- actually creating the thing isn't engineering design (only creating the plans to create it is engineering design).
- not all engineering work is **design**; PEO also lists the following as potentially engineering: planning, composing, evaluating, advising, reporting, directing, or supervising.
  - These other things still only count as engineering if they
    - require you to use "engineering principles" to do them, and
    - concern safeguarding of "life, health, property, economic interests, the public welfare, or the environment".

# Economic Analysis Terms

→**Decision Variable**

- Something you could change about your design (e.g., pipe diameter, bracket length, how much overlap there is in time between process A finishing and process B starting, etc.)

→**Performance Parameter**

- Something that describes how well the realized design works in a way that may be relevant to an end user
  - e.g., cost, weight, time it takes to finish a process, likelihood of success on a process, etc.
  - "Performance parameters" are more directly related to value and incorporated into the NVF via conversion factors than decision variables are.
- You usually can't control performance parameters directly – you can only control them indirectly through the decision variables.

# Economically Optimum Engineering Design

→**To use Engineering Economic Analysis to find the optimum solution:**

1. use **technical analysis** to determine how decision variables are related to each other and to performance parameters, then use this to
2. write the **NVF** (which is in performance parameter-terms) in terms of those decision variables, and finally
3. use **optimization methods** to determine
   1. the optimum set of decision variable values (i.e., the best **design**) subject to the problem's constraints,
   2. the corresponding value of the NVF at that optimum, and
   3. how sensitive the optimum set and resulting NVF are to changes in decision variables and other parameters of the problem (e.g., constraints, conversion factors, etc.)

**This is your overall objective in the 3PX project.**

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# Technical Analysis – Fluid Mechanics Example

# nanoRIMS Fluid Mechanics Tech Analysis - Setup

**→Which internal diameter *D* should we choose for the tube that nanoRIMS moves water through?**

**→Given that (i.e., assuming):**

1. We need a water flow rate of $\dot{\mathcal{V}}$ = 350 mL/min (5.83e-6 $m^3$/s),
2. The type of pumps we're using have a cost of $10 for every 10 mW of useful pumping output power, $\dot{W}_{pump,u}$,
3. NanoRIMS' estimated price point of $600 was assuming a $10 pump (i.e., 10 mW)
4. We need to pump water from a reservoir through an *L* = 30 cm tube that is a max of $\Delta z = 20$ cm higher in elevation at the exit,
5. 5 cm of the tube at the outlet may or may not empty into the mixing chamber after using the pump, creating some uncertainty in amount of water we get, and
6. We need mL precision in amount of water we added - every mL off from perfect we add a 2% chance the batch is unsuccessful

# nanoRIMS Fluid Mechanics Tech Analysis - Results

→**We can determine using *technical analysis* (based on a fluid mechanics course) that:**

- Pumping power required is: $\dot{W}_{pump,u} = \rho\dot{\mathcal{V}}\left(\frac{32\dot{\mathcal{V}}}{\pi D^4}\left(\frac{\dot{\mathcal{V}}}{\pi} + 12\nu L\right) + g\Delta z\right)$, i.e., more diameter means lower power required and therefore lower cost (cheaper pump possible), at least around ID of 1/8" (*D* = 0.00635 m) and smaller.
- where:
  - $\dot{\mathcal{V}} = 350$ mL/min $= 5.83$e−6 $\mathrm{m}^3/s$ is the volumetric flow rate,
  - $\rho = 1000$ kg/m$^3$ and $\nu = 1$e−6 m$^2/s$ are the density and kinematic viscosity of water,
  - $g = 9.81$ m/s$^2$ is the Earth's gravitational acceleration,
  - $L = 30$ cm is the length of the tube,
  - $\Delta z = 20$ cm is the (max) elevation change provided by the pump

# nanoRIMS Fluid Mechanics Tech Analysis – Impact

→Now based on the pump cost from pump power and error rate from pipe diameter conversion factors we had in the setup we can determine the cost implication (the pump and the error rate from the tube being too wide and maybe or maybe not dropping extra water):

$$\rightarrow \Delta Cst_{pump} = \frac{\$10 \cdot \frac{\dot{W}_{pump,u}}{\mathbf{mW}} - \$10}{\mathbf{yr}} \times \frac{1\ \mathbf{yr}}{52\ \mathbf{wk}} = \frac{\rho \dot{\mathcal{V}} \left( \frac{32 \dot{\mathcal{V}}}{\pi D^4} \left( \frac{\dot{\mathcal{V}}}{\pi} + 12 \nu L \right) + g \Delta z \right)}{10\ \mathbf{mW}} - \$10$$

$\rightarrow \Delta Cst_{\text{tube uncertainty failures}}$ = (# of batches per week)*(chance a specific batch fails)*(cost of redoing a batch)

- $= 2 * (2\% * \left(5\ \text{cm} \cdot \frac{\pi D^2}{4}\right) / 1\ \text{cm}^3) * \$23.75$
- $= \$1.1875 \frac{\pi D^2}{\text{cm}^2}$

# nanoRIMS Fluid Mechanics Tech Analysis – Impact

→Finally, adding these lets us see how the cost used in the NVF is impacted by the decision variables of "pipe internal diameter" (and has pointed out the dependence on some other parameters too)

→Cost per week = Original cost per week + $\Delta Cst_{pump} + \Delta Cst_{\text{tube diameter uncertainty}}$

$$= \$202.04 + \frac{\$10}{52} \times \frac{\dot{W}_{pump,u}}{10\ \text{mW}} + 2 \cdot \frac{\$23.75}{\text{wk}} \times 0.02 \frac{5\ \text{cm} \cdot \frac{\pi D^2}{4}}{1\ \text{cm}^3}$$

$$= \$202.04 + \frac{\$10}{52} \times \frac{\rho \dot{\mathcal{V}} \left( \frac{32 \dot{\mathcal{V}}}{\pi D^4} \left( \frac{\dot{\mathcal{V}}}{\pi} + 12 \nu L \right) + g \Delta z \right)}{10\ \text{mW}} + \$1.1875 \frac{\pi D^2}{\text{cm}^2}$$

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# Technical Analysis – 3PX3 Project Requirements

# 3PX3 Technical Analysis Requirements

→**Technical analysis you do in 3PX3 should**

- Use discipline-specific course content,
- Not require substantial time (e.g., more than 30 minutes) looking things up or learning new things, and
- Be relevant to your economic analysis.

# 3PX3 Technical Analysis Requirements

→**Technical analysis you do in 3PX3 should**

- Use **discipline-specific course content,**
  - Should be based on info you learned in one or more technical courses you took towards your engineering degree which fewer than 75% of other disciplines took as well.
    - e.g., CHEMENG 2O04, CIVENG 2C04, 2O03, 2P04, ELECENG 2CJ4, 2EK4, COMPENG 3DQ5, ENGPHYS 2P04, 2E04, 2CM4, MATLS 2Q03, 3M03, MECHENG 2P04, 3A03, MECHTRON 2TA4, SFWRENG 3DB3, 3DX4, etc. (many course options besides these)
      - (whether or not you're in the program whose name is the course code, if it's required for your program you can use it!  e.g., Matls can use CHEMENG 2O04, Mechatronics can use ENGPHYS 2E04, etc.)
    - but not, for e.g., MATH 2ZZ3, ENG 1P13, PHYS 1E03, etc. (these are taken by everyone)
- Not require substantial time (e.g., more than 30 minutes) looking things up or learning new things, and
- Be relevant to your economic analysis.

# 3PX3 Technical Analysis Requirements

→Technical analysis you do in 3PX3 should

- Use discipline-specific course content,
- Not require **substantial time** (e.g., more than 30 minutes) **looking things up** or learning new things,
  - (otherwise, you didn't really know how to do it with your coursework)
  - Time to ***review*** things from the courses you forgot how to do is OK
  - *Some* time to learn new things is OK (but not expected) as long as your courses *enabled* you to interpret and apply it in a way that someone without those courses wouldn't be able to do
  - Instead of looking up lots of data, ***make an assumption and move on!***
    - The point is *not* that you get perfect numbers and results - You just need to show by what you produce that
      - you know how to do engineering technical analysis, and
      - you know how to apply this in the service of optimizing an NVF.
- Be relevant to your economic analysis.

# 3PX3 Technical Analysis Requirements

→**Technical analysis you do in 3PX3 should**

- Use discipline-specific course content,
- Not require substantial time (e.g., more than 30 minutes) looking things up or learning new things, and
- Be **relevant to your economic analysis**.
  - i.e., enables you to link decision variable(s) to performance parameters your NVF cares about
  - Enable you to rewrite the NVF in terms of decision variables, and later **optimize** NV of your solution (using optimization techniques on the NVF to determine the best combination of decision variable values considering their impact on each other and on performance parameters that you revealed with your technical analysis and surrounding assumptions)

NOTE: sometimes tech analysis can result in a **design choice**, e.g., "which diameter should we use to get exactly 10 mW of required pumping power?" The tech analysis you'll do for 3PX **shouldn't** do this directly, it should instead determine a **relationship** between variables, e.g., "how is required pumping power *related* to internal pipe diameter?". The actual design choice of which pipe diameter to use should come from optimizing the NVF.

→

- Be **relevant to your economic analysis**.
  - i.e., enables you to link decision variable(s) to performance parameters your NVF cares about
  - Enable you to rewrite the NVF in terms of decision variables, and later **optimize** NV of your solution (using optimization techniques on the NVF to determine the best combination of decision variable values considering their impact on each other and on performance parameters that you revealed with your technical analysis and surrounding assumptions)

# 3PX3 Technical Analysis Requirements

→**Note - Validity & assumptions:**

- Likely your result will push totally to one extreme (e.g., make this variable as large or small as possible), but ask yourself: is that *valid*? There's probably a tradeoff somewhere, so find a way to build that in (again, making generous amounts of assumptions)
  - e.g., from a pumping-power perspective, analysis says make the tube as large as possible. But that would probably increase uncertainty in amount of flow, cost more space, require a more expensive tube, etc. Therefore, build in some calculation that incorporates one or more of these limits so the optimization can work.