ENG 3PX3 - Engineering Economics

McMaster University

Engineering Economics & Net Value Applications

Engineering Economics

→**Engineering economics deals with the techniques of quantitative analysis to determine the economically 'best' alternative**

→**How can you decide on whether your company should undertake an engineering project?**

- Determine the benefits it will lead to compared to the costs you'd pay to realize those benefits.
- If the net value (=benefits – costs) is positive, it is worthwhile to undergo the project

Engineering Economics

→**How do we compare between mutually exclusive alternatives?**

- Determine the net value of each alternative (relative to some consistent reference, possibly one of the alternatives used as a “benchmark” or “default option”)
- Select the alternative with the best net value

→**In this lecture, we will go through an in-depth example of using net value to make decisions between alternative choices**

Net Value Example: nanoRIMS

→**Scenario: A lab needs gold nanoparticles for research purposes (200 mL/week of 20 nm ± 1 nm diameter OD 1)**

- We can **buy** them, but it's expensive
- We can have a grad student **fabricate** them, since the ingredients are cheap, but this uses more time and occupies the whole fume hood
- We might be able to **make a device that automates** the fabrication, but this takes some R&D work, costs a lot of money initially, may break down from time-to-time, and takes up some fume hood space

→**Problem: Should we purchase the gold nanoparticles, fabricate them manually, or build a device to fabricate them automatically?**

Net Value Functions

→To make an economic decision about which option is best, we need to determine which option has the most positive net value for the lab

→We combine this information into a single expression called a ***Net Value Function*** (***NVF***)

$$Net\ Value_{Lab} = Benefits_{Lab} - Costs_{Lab}$$

$$Net\ Value_{Lab} = Benefits\ of\ Nanoparticles\ - Cost\ of\ Ingredients, Time, Space, \ldots$$

→To find the difference between the benefits and costs, we need to have all our terms in the same units, e.g., *dollars worth of value per week*

Unit Conversions

→**Recall:**

- We can have a grad student fabricate them, since the ingredients are cheap
  - But this uses more time and occupies the whole fume hood

→**So,**

- NV of having the grad student make them [compared to not having them at all] is:
  - Benefit of getting nanoparticles – cost of (grad student time, ingredients, fume hood space used)

→**But we can't add these yet... just like you can't add 5 m to 3 kg.**

→**To find the difference between the benefits and costs, we need to have all our terms in the same units, e.g., *dollars worth of value per week***

nanoRIMS Unit Conversion Rates

→**Suppose we do research and analysis, and determine the following conversion factors (from the perspective of the research lab):**

- Cost to purchase nanoparticles: $112 for 25 mL
- Cost to fabricate nanoparticles in lab:
    - **Ingredients: $5 per 100 mL of nanoparticles fabricated.**
    - **Fume hood time (whole): $12.50/hr**
    - **SEM time (to check for quality): $100/hr**
    - **Grad Student time: $15/hr**

Examples of **unit conversions,** evaluating the **cost of time** or the **cost of space**, etc.

Unit Conversion Rates

→**Some unit conversion rates are easy to determine**

- e.g. fume hood rental is at a fixed rate

→**Some unit conversion rates are more subjective**

- e.g. grad student time: how would we determine the value of the grad student time? Hourly wage? Hourly wage + what they can be doing with that time instead (i.e. opportunity cost, more on this later)

→**As engineers we must make educated estimates on unit conversion rates**

nanoRIMS Solution Details & Comparison

→**If the grad student produces the nanoparticles, they need:**

- 9 hours of their time, including 8 hours occupying the fume hood, and 30 minutes using the SEM

→**If we build a device ("nanoRIMS"):**

- An automated desktop system that fits inside one cubic foot, costs $600, is expected to work for 1 year of regular use, and can produce and characterize at least 200 mL of gold nanoparticles per week
- The system will require only minimal grad student interaction (30 minutes per day, 5 days/week.) It will use similar amounts of supplies as a grad student would and pose no inconvenience or safety hazards to the lab

→**Question: if both deliver the same benefit, which of these two alternatives should we choose?**

Net Value Example: nanoRIMS

→**Recall:**

$$Net\ Value = Benefits - Costs$$

→**In our example, it is "easy" to calculate the <u>cost</u> per week for purchasing or fabricating the gold nanoparticles**

→**However, it is hard to quantify the <u>benefits</u> of "getting the nanoparticles" vs "not getting them at all"**

- *What is the value of being able to do research with the gold nanoparticles?*

Net Value Example: nanoRIMS using a benchmark

→**Net Value created (for the lab, per week) by *purchasing* the nanoparticles is**

$$NV_P = B_P - C_p$$

- Where NV_P is Net Value of purchasing, B_P is the benefit of purchasing and C_P is the cost of purchasing

→**Similarly, for *fabricating* them manually, we have:**

$$NV_F = B_F - C_F$$

→**And for using *nanoRIMS* we have:**

$$NV_{nR} = B_{nR} - C_{nR}$$

→**Assuming all 3 solutions will give the same quality of nanoparticles,**

$$B_P = B_F = B_{nR}$$

Net Value Example: nanoRIMS using a benchmark

→**Even if we don't know what the benefit *is*, we can still determine which of the solutions is best by finding the net value each produces *compared to* any other one, e.g., compared to purchasing:**

- $NV_P(relative\ to\ purchasing) = NV_P - NV_P = 0$
- $NV_F(relative\ to\ purchasing) = NV_F - NV_P = C_P - C_F$
- $NV_{nR}(relative\ to\ purchasing) = NV_{nR} - NV_P = C_P - C_{nR}$

→**So, (as long as we're going to do *any* of these rather than scrapping the research all together), we'd do the one with the most positive net value (relative to any consistent benchmark).**

- This is the same one as the one with the most positive NV relative to purchasing the nanoparticles
- In this case (since all have the same benefit), the one with the most positive NV is the same as the one with the lowest cost.

Exercise

→**What does it mean if we find both** $NV_{nR}(relative\ to\ purchasing)$ and $NV_F(relative\ to\ purchasing)$ are negative?

a) we should not do any of these solutions

b) if we're going to get nanoparticles, we should choose the least negative of the two

c) if we're going to get nanoparticles, we should choose the largest of the two, even if it's negative

d) if we're going to get nanoparticles, we should purchase them

Forming the Net Value Function

→**Relative to purchasing,**

- $NV(relative\ to\ purchasing) = C_P - C$

→**Cost of purchasing is:** $C_P = \frac{\$112}{25\ \text{mL}} \times 200\ \text{mL} = \$896/\text{week}$

→**Cost depends on how much ingredients, grad student time, SEM time, and space we require**

- Ingredients: $5/100 mL produced (or possibly more if we waste ingredients)
- Fume hood time: $12.50/hr (multiplied by the fraction of the fume hood we're using)
- SEM time (to check for quality): $100/hr
- Grad Student time: $15/hr

→**Therefore, (using purchasing as a benchmark) the <u>net value function</u> is:**

- $NV = \frac{\$896}{\text{week}} - \left(\frac{\$5}{100\ \text{mL}} q_{ingred} + \frac{\$12.5}{\text{hr}} \times t_{FumeHood} + \frac{\$100}{\text{hr}} \times t_{SEM} + \frac{\$15}{\text{hr}} \times t_{GradStudent} + C_{other}\right)$

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NVF example: Fabricating nanoparticles

→**For fabricating:** $NV_F(relative\ to\ purchasing) = C_P - C_F$

→**Cost of purchasing is:** $C_P = \frac{\$112}{25\ \text{mL}} \times 200\ \text{mL} = \$896/\text{week}$

→**Cost to fabricate in lab (per 100 mL)**

- Ingredients: $5
- Fume hood time: 8 hrs @ $12.50/hr
- SEM time (to check for quality): 30 min @ $100/hr
- Grad Student time: 9 hours @ $15/hr

→**Therefore,** $C_F = 2 \times \left(\$5 + 8\ \text{hr} \times \frac{\$12.5}{\text{hr}} + 0.5\ \text{hr} \times \frac{\$100}{\text{hr}} + 9\ \text{hr} \times \frac{\$15}{\text{hr}}\right) = \$580/\text{week}$

→Or,

- $NV = \frac{\$896}{\text{week}} - \left(\frac{\$5}{100\ \text{mL}} 200\ \text{mL} + \frac{\$12.5}{\text{hr}} \times 16\ \text{hr} + \frac{\$100}{\text{hr}} \times 1\ \text{hr} + \frac{\$15}{\text{hr}} \times 18\ \text{hr} + \$0\right)$

NV of Manually Fabricating nanoparticles

→Putting it all together to calculate the net value of fabricating

$$NV_F(relative\ to\ purchasing) = C_P - C_F$$

$$NV_F(relative\ to\ purchasing) = \frac{\$896}{\text{week}} - \frac{\$580}{\text{week}} = \frac{\$316}{\text{week}}$$

→Therefore, we can say that fabricating the nanoparticles is better than buying them

→But is it better than automating the fabrication with the nanoRIMS device?

Costs for Automating Solution (nanoRIMS)

→**Determining costs associated with a nanoRIMS:**

- Cost of consumables
  - Ingredients: \$5/100mL × 200 mL/week = \$10/week
- Cost of time
  - Grad student: \$15/hr × 0.5 hr/day × 5 days/week = \$37.50/week
- Cost of space
  - Fume hood: \$12.50/hr × 14 hr/day × 7 days/week × 1/8 = \$153/week
- Cost of characterization
  - \$0 (self-characterization)
- Cost of the device
  - \$600/year = \$11.54/week
- Total cost: \$212.04/week

Net Value Example: nanoRIMS

→**Putting it all together for nanoRIMS**

$$NV_{nR}(relative\ to\ purchasing) = C_P - C_{nR}$$

$$NV_{nR} = \frac{\$896}{\text{week}} - \frac{\$212.04}{\text{week}} = \frac{\$683.96}{\text{week}}$$

Recall: $NV_F(relative\ to\ purchasing) = \frac{\$896}{\text{week}} - \frac{\$580}{\text{week}} = \frac{\$316}{\text{week}}$

→**The nanoRIMS proposed solution has a better NV than the existing solutions, therefore it is worth pursuing**

Net Value Function

$$NV = \frac{\$896}{\text{week}} - \left(\frac{\$5}{100\ \text{mL}} \times q_{ingred} + \frac{\$12.5}{\text{hr}} \times t_{FumeHood} + \frac{\$100}{\text{hr}} \times t_{SEM} + \frac{\$15}{\text{hr}} \times t_{GradStudent} + C_{other} \right)$$

→**Checks of a Net Value Function:**

1. Edge cases (does it correctly dismiss crazy ideas that definitely won't work?)
2. Scaling (does it reflect the real change in value from a given change in a performance metric?)
3. Reality checks (does it *feel* right?)
4. Be willing to estimate things when you don't know them, just acknowledge the estimate and do focused research to help resolve it when possible / necessary
5. Be willing to return to re-framing the problem if you need more information

Constraints and Conversion Factors

→When doing an economic analysis (i.e., creating a NVF and substituting in alternatives to make a decision), **anything that's relevant & important enough to mention in the analysis** needs to be either:

- **Explicitly incorporated** into the NVF **by giving it a conversion factor** to turn amounts of it into a common unit (i.e., money) so you can compare relative benefits & costs of different levels of it to those of any other relevant parameters, **AND/OR**
- **Included as a hard constraint**, a requirement that the solution is rejected if it is not within certain range of values of the parameter
  - e.g., max value: If the solution weighs more than 10 kg, we will reject it
  - e.g., specific value: it must make exactly 200 mL of acceptable nanoparticles per week

Exercise:

→**Detect hard constraints vs. conversion factors:**

→**State whether each of the following are hard constraints, conversion factors, both, or neither:**

- $15 cost/1 hour of grad student time
- If only occupying 1 fume hood, $12.50 cost/1 hour of fume hood time
- $896 saved/week for every 200 mL of nanoparticles we do not need to purchase
- Device must have a mass of < 10 kg
- Must have an output voltage of 5 V

Constraints for nanoRIMS

→Constraints for a potential solution:

- Must not occupy more than one fume hood worth of space
- Must be safe enough to be used in the lab
- Must not be disruptive to work happening elsewhere in the lab (e.g., produce noise louder than fume hood fans, produce disruptive odors, etc.)
- …and it must provide exactly 200 mL of acceptable nanoparticles per week

Net Value Functions Recap

$$NV = Benefits - Cost$$

$$= \frac{\$896}{\text{week}} - \left(\frac{\$5}{100\text{ mL}} q_{ingred} + \frac{\$12.5}{\text{hr}} \times t_{FumeHood} + \frac{\$100}{\text{hr}} \times t_{SEM} + \frac{\$15}{\text{hr}} \times t_{GradStudent} + C_{other}\right)$$

→**Need**

- a clear **benchmark**: Benefit & cost of this *compared to what*?
- a clear **perspective** or **scale**: Benefit & cost for *which party* (or *combination of parties*)?
- a consistent set of **units** (e.g., time, money, etc.)

→**It is OK to estimate!**

- Just acknowledge it and be ready to revisit it if you need to
- *All models are wrong, but many are still useful*

Net Value Functions Recap

$$NV = Benefits - Cost$$

$$= \frac{\$896}{\text{week}} - \left(\frac{\$5}{100\text{ mL}} q_{ingred} + \frac{\$12.5}{\text{hr}} \times t_{FumeHood} + \frac{\$100}{\text{hr}} \times t_{SEM} + \frac{\$15}{\text{hr}} \times t_{GradStudent} + C_{other}\right)$$

→**Note: To substitute a set of solution parameters (e.g., q_{ingred}, $t_{FumeHood}$, C_{other}, etc.), we also need a way to determine which combinations of those input parameters are valid (e.g., is there some option to use 0 grad student time, ingredients, or other cost?)**

- Some information here comes from constraints
- We can sometimes relate parameters together with the help of **technical analysis** (next week)