Week 2

Overview and Goals

- Introduce the recycling project.
- Construct a rudimentary framework to evaluate and rank proposed designs.
- Introduce unitless cost equations.
- Construct a rudimentary unitless cost equation.

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Nomenclature, Definitions, and Abbreviations

Nomenclature

d – Design

$mult$ - Multiplier

$NumW$ - *Number of Workers*

$SA, SB, \wedge SC$ - Design A, B, and C

ST - *Sorting Time*

Definitions

Cost Equation – An equation that evaluates a design based on the idea that a design that costs less (lower cost) is better.

Objective – Something a design should have.

Metric - A quantitative value we can use to measure/evaluate designs that incorporate parameters. E.g. a total time for the process that incorporates each sub-process.

Normalized – Quantities that are scaled to some common factor, usually so they can be compared.

Parameter - Physical/functional characterises of a design used as inputs to the design process. E.g. the total time for a sub-process to finish.

Unitless – A dimensionless quantity having no units of measurement. For example, a ratio, percentage, or relative scale, such as decibels.

Abbreviations

h - Hour

kg - Kilogram

kW - Kilowatt

MRF – Materials Recovery Facility

- Number

Background and Motivation

For standard municipal waste handling and collection, costs can represent nearly two-thirds of waste management spending. Many municipalities have begun moving towards systems which avoid complicated and expensive curbside collection programs. This has resulted in mixed-recycling collection programs where all recyclable material, glass, steel, aluminum, mixed paper, and plastic, are sorted into one blue-bin collection, while garbage and organics remain separate. This is all then sent to a materials recovery facility (MRF), which separates recycling material from waste [1]–[7] (Figure 1). This streamlines the recycling process and captures any recycling that would otherwise be incorrectly sorted and lost. The Hamilton municipal government has decided to shift to this mixed-recycling system and wants to create a new MRF facility near the Ancaster neighbourhood and the Dundas Valley Conservation Area.

Figure 1. General Materials Recovery Facility [8].

An MRF (Figure 2) will generally include a tipping floor, which collects materials, containing recycling and residual materials, before being sent into the sorting process. The sorting process for materials is done through the following steps:

0. The recycling waste is first loaded onto conveyors by manned forklifts.
1. The waste goes through a **pre-sort step** in preparation for sorting, where large waste is removed, bags are ripped open, and waste is fed to the process. This can be done either manually or with automated machinery.
2. The waste passes through a **paper sorting step**, where materials like paper, newspaper, and cardboard are removed and sent to the sorted paper bin.
3. The remaining waste is sent to the **glass fine screens**, where it passes over screens that filter out glass pieces that go to the sorted glass bin.

4. The rest of the waste goes through a large magnet in the **magnetic separation step**, which removes ferromagnetic material to be sorted out to its corresponding bin.
5. Next, the waste goes through **plastic classifiers**, and all plastic is removed.
6. Any remaining waste is considered **residual**, which is sent to a garbage dump.
7. Finally, all the sorted recycling waste bins are removed and processed for recycling.

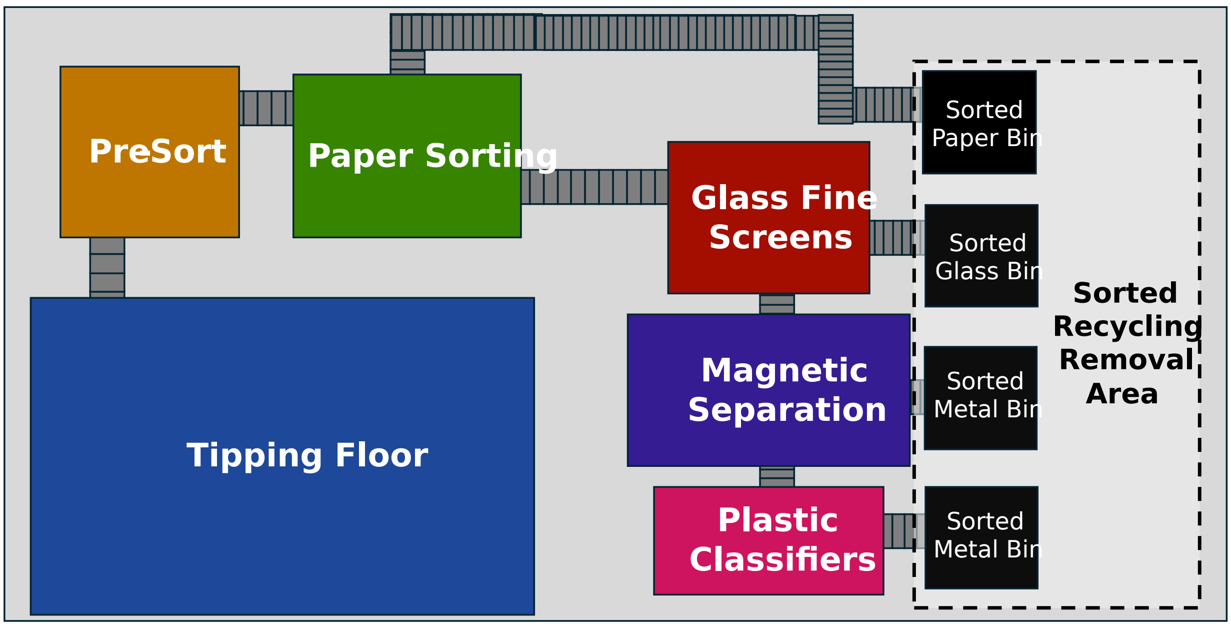

Figure 2: Detailed layout of the general MRF process.

You have been tasked by the Hamilton Municipal Government to decide the layout of the new MRF. Designing the facility is out of scope for this Project. However, you will act as an engineer contracted to evaluate potential designs drafted with the necessary steps required for sorting daily incoming recycling. They hope to use your expertise and recommendation to decide between three different potential designs. You will go through the process of creating a system to make this decision over the following couple of weeks and present a formal recommendation on which one is the best fit.

You'll be able to discuss options with the people at your table, but the work you do on these worksheets will be yours, and yours alone. If successful, the Ontario government will consider implementing MRF programs provincially. Therefore, you'll want your evaluation framework to apply to many different locations, not just a singular one.

Exercise 1

You have found five MRF designs based on a simplified process (Figure 3) of potential layouts the MRF might adopt. Let's evaluate which one is the best! Initially, we are only concerned with the time it takes the MRF to sort the total waste collected.

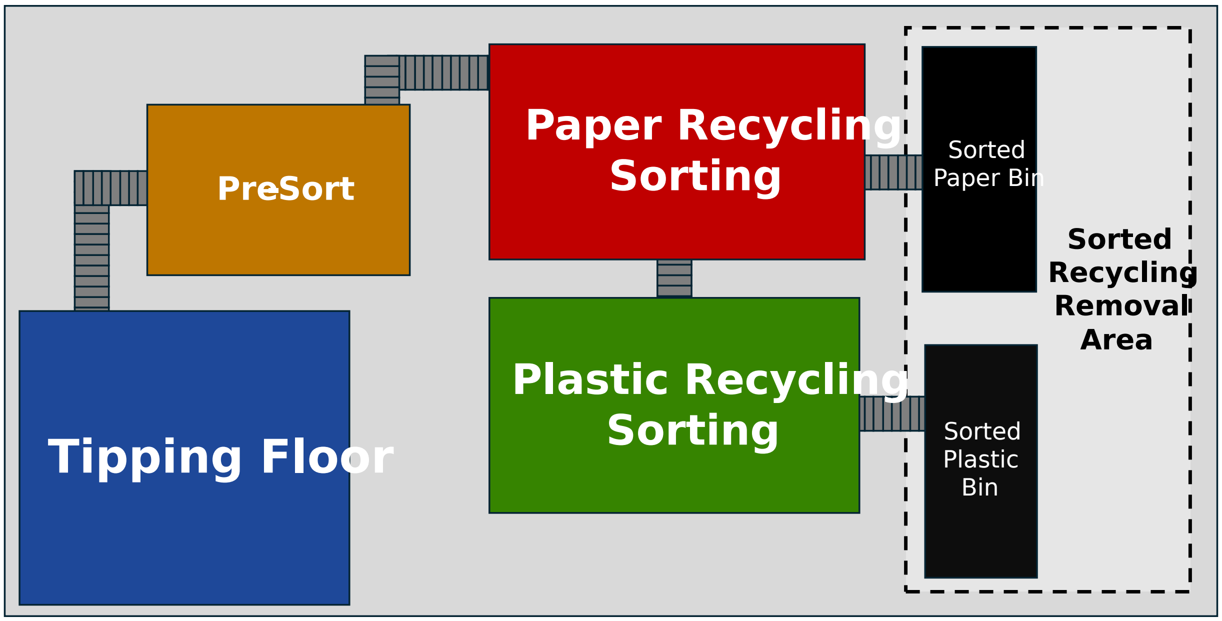

Figure 3: MRF general layout diagram.

There are 15 trucks filled with waste collected daily, each carrying a maximum of 15,000 kg of recycling, which will dump their waste on the tipping floor to await sorting. Consider the total sorting time to be the first **metric** for our evaluation framework. This means we will judge designs solely on time, with faster being better. Which of the five designs, A-E, is the best in this case?

Calculating Sorting Time

To determine the time taken to sort, assume all 15 trucks are full of 15,000 kg of waste each. Then consider how much time each step takes and sum them for our total. The sorting rate and amount of waste being sorted determine the time for that step.

Note: Each step sorts out the corresponding waste type, therefore reducing the amount of waste that moves on to the next step.

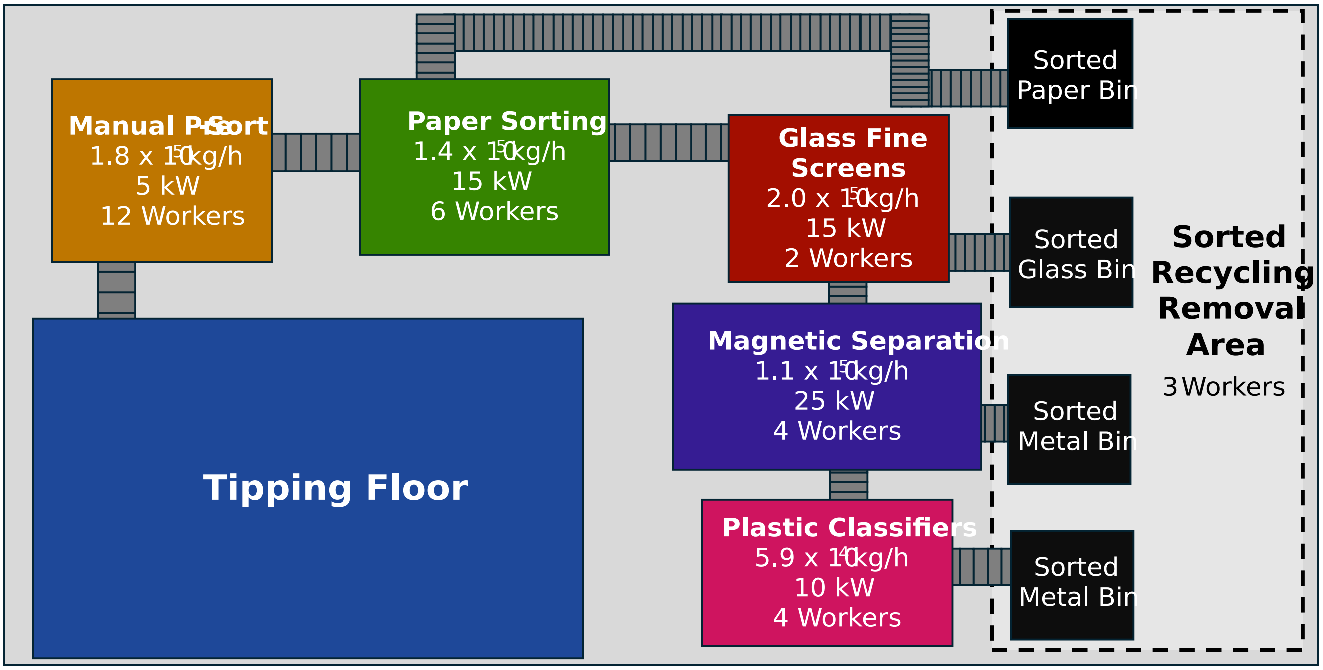

Figure 4: Detailed layout of MRF design SA.

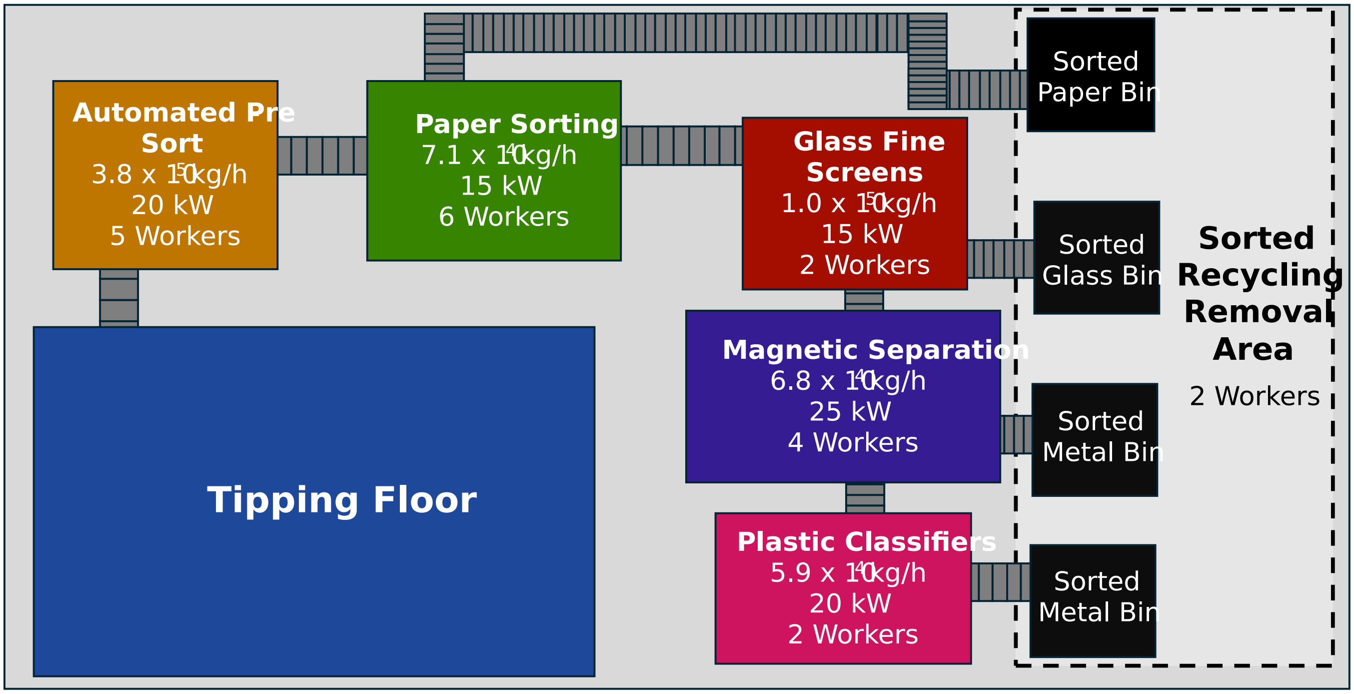

Figure 5: Detailed layout of MRF design SB.

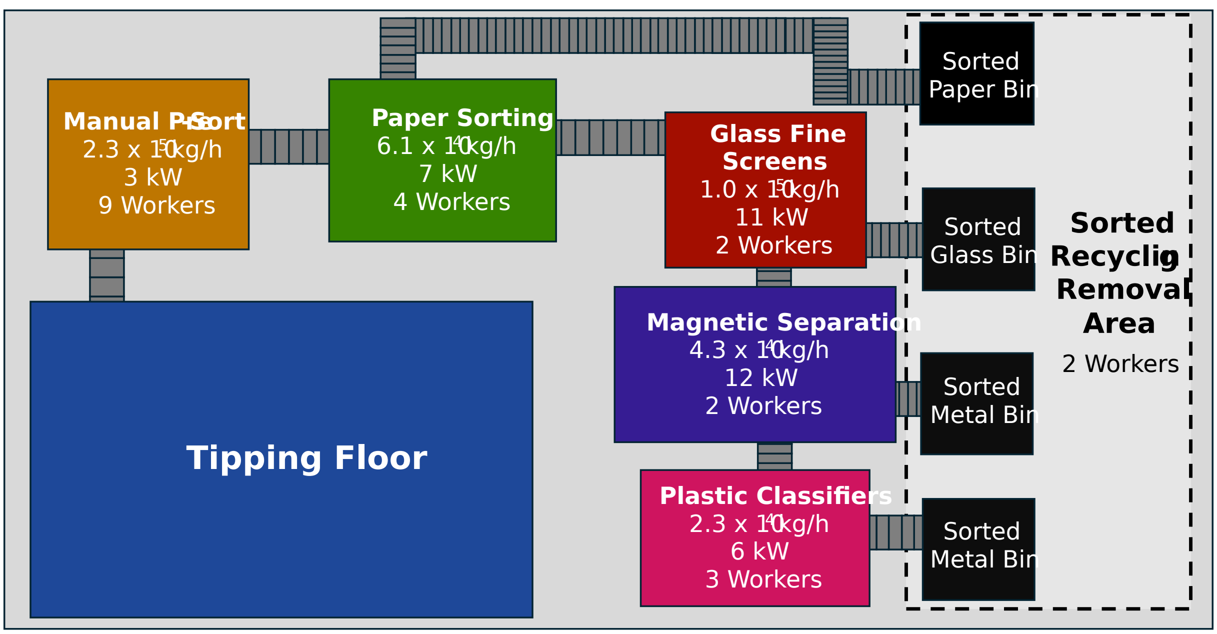

Figure 6: Detailed layout of MRF design SC.

As we begin Project 1, we also recommend that you start familiarizing yourself with your Project 2 group members and begin gathering preliminary information. Coming into Design Studio with early research already completed will give you a strong starting point for group discussions and allow you to move through the design cycle more efficiently.

Starting this week, your group should begin holding **weekly meetings** and **recording meeting minutes**. You are free to use the template provided on Avenue for recording these meeting minutes. For more information about Project 2 and expectations for meetings held outside of Design Studio, please refer to the *Pre-Project 2 Introduction* document available on Avenue.

References

[1] “The Evolution of Mixed Waste Processing Facilities: 1970 – Today,” Gershman, Bricker, & Bratton Inc., Solid Waste Management Consultants, Fairfax, VA., Jun. 2015.

[2] “Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures,” U.S. Environmental Protection Agency Office of Resource Conservation and Recovery, Apr. 2014.

[3] “Positive Sorting - The MRF of the Future,” Van Dyk Recycling Solutions. [Online]. Available: https://vdrs.com/positive-sorting/. [Accessed: Ma-2020].

[4] E. Pollock, Team Lead, Waste Processing and Disposal, Region of Peel, private communication, Ma. 2020.

[5] “Region of Peel, Material Recovery Facility Efficiency Assessment and Improvement Recommendations,” Reclay StewardEdge and Holiday Recycling Technologies, Jan. 2017.

[6] “Regional Municipality of Waterloo, Process/Equipment Review, Material Recycling Centre (MRC),” Reclay StewardEdge and Holiday Recycling Technologies, Ma. 2017.

[7] “Durham Region MRF Container Line Productivity and Efficiency Upgrade,” Continuous Improvement Fund, Steve Jedinak, Sept. 2019.

[8] “What Is a Materials Recovery Facility (MRF)? | Rubicon.” Accessed: Jun. 22, 2025. [Online]. Available: https://www.rubicon.com/blog/materials-recovery-facility/

Appendix

Normalized Unitless Cost Equations Development

Cost Equations

A cost equation is a tool engineers use to evaluate different designs based on measurable factors, such as efficiency, durability, and optimization. It considers aspects relevant to objectives and measures their impacts. This lets engineers quantitatively measure the trade-offs between different design choices and determine the best solution based on a numerical value.

The reason engineers call it a “cost” equation, despite not just measuring monetary cost, is that we are evaluating the cost of each decision to the total design. So, higher values in a cost equation indicate more drawbacks and a less optimal design. Think of the cost as a score that shows how much the design “takes” from the most optimal design. This is important to consider because when creating our cost equations, we always want our calculated cost to decrease with better design choices.

Let’s use an example! A simple version of a cost equation for our MRF could be (Equation A1):

$$Cost = total\ sorting\ time + number\ of\ workers$$

Equation A 1 - General cost equation to evaluate MRF designs.

In this equation, we have two design parameters: *total sorting time* and *number of workers*. If either one increases, this is undesirable because we want a quick design with minimal workers. So, as a result, when either increases, our resulting cost also increases, reflecting a greater loss in the optimal solution.

Unitless Cost Equations

There are two issues with this equation, though:

- The units are not the same. *Total sorting time* is measured in hours whereas *number of workers* is a unitless value. We cannot add values mathematically with different units.
- The scale of time compared to workers is different, making the impact of workers on the total cost insignificant.

Let's explore how to fix these problems!

Firstly, let’s look at units (Equation A2). As mentioned, the unit of *total sorting time* is in hours, and the number of workers is unitless.

$$Cost = total\,sorting\,time\,(h) + number\ of\ workers\,(unitless)$$

Equation A 2 - General cost equation to evaluate MRF designs with units.

Mathematically, we cannot add these values together because they are incompatible measurements. Instead, we want them both to be unitless. Luckily, the *number of workers* is already unitless, so we just need to make the *total sorting time* unitless as well.

To make *total sorting time* unitless, we need to cancel out the hour unit. One way to do this is to simply divide it by 24 hours, the number of hours in the day. You could also use 8 hours, which is the hours in a workday for a standard shift, or 40 hours as the number of work hours in a week. You can divide by whatever value you want as long as you're consistent with that value for all calculations and the scaling works out (more on that soon) (Equation A3).

$$Cost = \frac{total\,sorting\,time\,(h)}{24\,(h)} + number\ of\ workers\,(unitless)$$

Equation A 3 - Updated cost equation to evaluate MRF designs with cancelling units.

So, the units of this equation (Equation A4) become:

$$Cost = \left[\frac{total\,sorting\,time \in hours}{24}\right](unitless) + number\ of\ workers\,(unitless)$$

Equation A 4 - Updated cost equation to evaluate MRF designs with updated units.

Normalization of Unitless Cost Equations

Now, we have a unitless equation! Let's move on to the next problem, scalability, also known as **normalization**. If we had two designs with the following values:

Table A 1: Design variables.

Design	Total sorting time (h)	Number of workers
A	3	5
B	8	4

And we calculated the unitless cost values for both:

Table A 2: Design cost calculations of Table A 1.

Design	Cost equation	Cost Score
A	$Cost=\left[\frac{3}{24}\right]+5$ $Cost=0.124+5$	5.125
B	$Cost=\left[\frac{8}{24}\right]+4$ $Cost=0.33+4$	4.33

You can see (Table A2) that the cost score contribution between hours and workers is very skewed. Despite Design A being 5 hours faster than Design B, Design B is considered significantly better based on the score (**Remember:** the higher the value, the worse the design). The number of workers in this equation is the only real determining factor of the design choice because of how much larger they are in comparison to the time value. However, we want both choices to be considered.

We can do this by incorporating multipliers or other design aspects. This multiplier is based on the evaluator's perspective on which choices are more important than others.

If we care a lot more about sort time but still want the number of workers to have an effect, we can multiply the time value by a large value. The exact value is a judgment call based on what you think is an appropriate relationship between design parameters.

For example, if we decided that an increase of one hour of sorting time, ST, had the same cost as an increase of 2 workers, $NumW$, then we could calculate a multiplier, $mult$, to represent this relationship. We can set the costs equal, substitute, and then solve for a multiplier, $mult$:

$$Cost = cost\ of\ sort\ time + cost\ of\ workers$$

$$Cost = mult \times \left[\frac{ST}{24}\right](unitless) + Num\,W\,(unitless)$$

$$Cost\ of\ 1\ hour\ of\ sorting\ time = cost\ of\ 2\ workers$$

$$mult \times \left[\frac{ST}{24}\right] = Num\,W$$

$$mult \times \left[\frac{1}{24}\right] = 2$$

$$mult \cong 50$$

Equation A 5 - Derivation to calculate multiplier mult.

Therefore, a multiplier of around 50 will allow our cost calculation to better reflect the influence the design choices should have on the design. Remember, we can only do this because we made the terms unitless in the previous section (Error: Reference source not found).

Now, let's add a multiple of 50 to the time in the equation and redo our calculations!

$$Cost = 50 \times \left[\frac{Total\ ST}{24}\right] + NumW$$

Equation A 6 - Updated cost equation to evaluate MRF designs with a multiplier.

Table A 3 - Updated with a normalized cost equation.

Design	Cost equation	Cost Score
A	$Cost = 50 \times \left[\frac{3}{24}\right] + 5$ $Cost = 6.25 + 5$	11.25
B	$Cost = 50 \times \left[\frac{8}{24}\right] + 4$ $Cost = 16.5 + 4$	20.5

We can then substitute the values for our two designs and compare again. Now that we have normalized our costs, design A has a better cost score (Error: Reference source not found) as we intended.

If you'd like to jump back to Exercise 3, you may click HERE.