THE UNIVERSITY OF UTAH

DEPARTMENT OF MECHANICAL ENGINEERING

ME 4000
Engineering Design I

Assignment 2 – Existing Solutions; Engineering Design Specifications (70 points)

Due date: See CANVAS for submission deadline and instructions

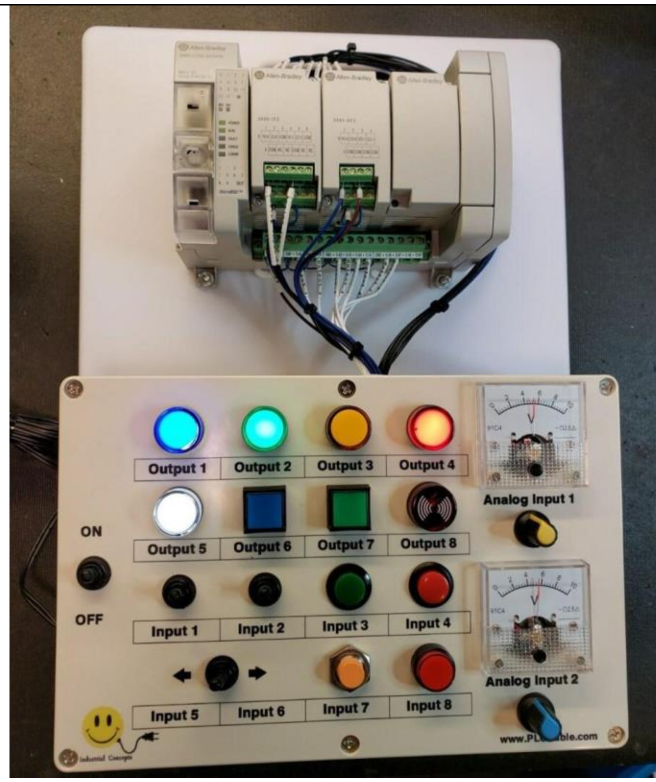
Objective: The goal of this assignment is to study relevant existing solutions, and to further define the design problem by developing engineering design specifications which are used to quantify performance levels needed to satisfy user needs.

A. Existing Solutions (/20 points)

1. Complete a table similar to the one below for **5 relevant existing design concepts** (4 points per concept examined). Existing design concepts can include any designs or mechanisms that currently exist and may be able to be applied to your design problem, either in full or in part (e.g. analogous mechanisms, devices used for similar function in other applications, block diagrams of existing control systems, similar relevant materials (e.g. composites – describe material properties), etc.). They may also be current solutions to the design problem that require improvement.

Concept 1 (/5 points)

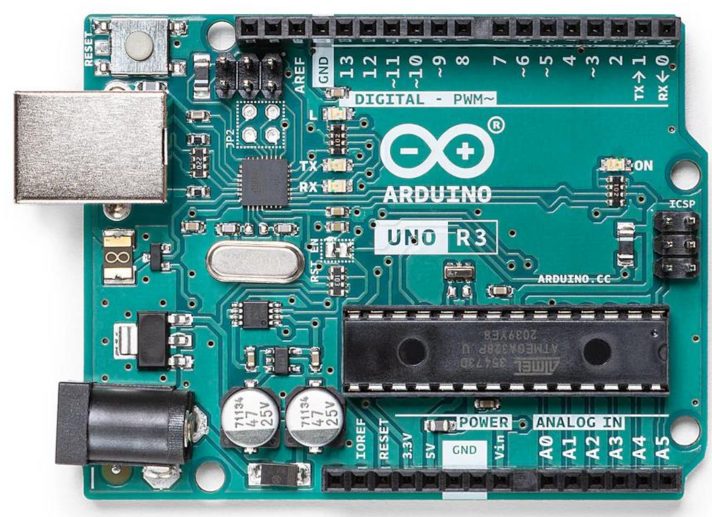
i. What is the design concept? Describe in 1-2 sentences. (/1 point)	This design is the Allen Bradley Deluxe Analog Trainer Micro850 CCW PLC Training Device. This device is an Allen Bradley PLC mounted to a board; electrically connected to 8 digital outputs with 2 analog outputs, and to multiple digital inputs with 1 analog input.
ii. How is the existing design concept relevant to your design challenge? (/1 point)	This is relevant to our design challenge as we have been tasked with creating a similar PLC trainer for instructing students in a future course. It accomplishes a similar goal.
iii. How does the existing concept work? Provide photos or sketches to explain how this concept works. (/1 point)	This concept is an Allen Bradley PLC preassembled with several inputs and outputs. This allows the user to easily check their PLC ladder logic using simple inputs and outputs. Users can easily program the PLC without getting into the complexities of wiring.

	
iv. What are pros/cons of this existing design solution? (/1 point)	Some pros of this design are that it is not overwhelming for a new user, it is very compact and easy to move, and it has the PLC itself easily accessible for users to interact with. Some cons of this design are that the inputs and outputs are overly simplistic (specifically analog), it does not allow for users to easily connect additional inputs/outputs, it is not brand agnostic, it does not allow for expansion of the PLC unit, and it lacks an HMI.
v. Could you apply this existing design concept in your project? What are the limitations of applying this existing design concept to your design problem? Could it be adapted? (/1 points)	Parts of this design could be adapted to work for our specific challenge. An extremely portable PLC trainer with a variety of inputs and outputs is a goal of ours. The limitations of applying this design entirely to our challenge is that it lacks an HMI and does not allow students to experiment with multiple different modules. The core ideas of this concept can be applied to our challenge, yet must be expanded upon to ensure successful completion of our task.

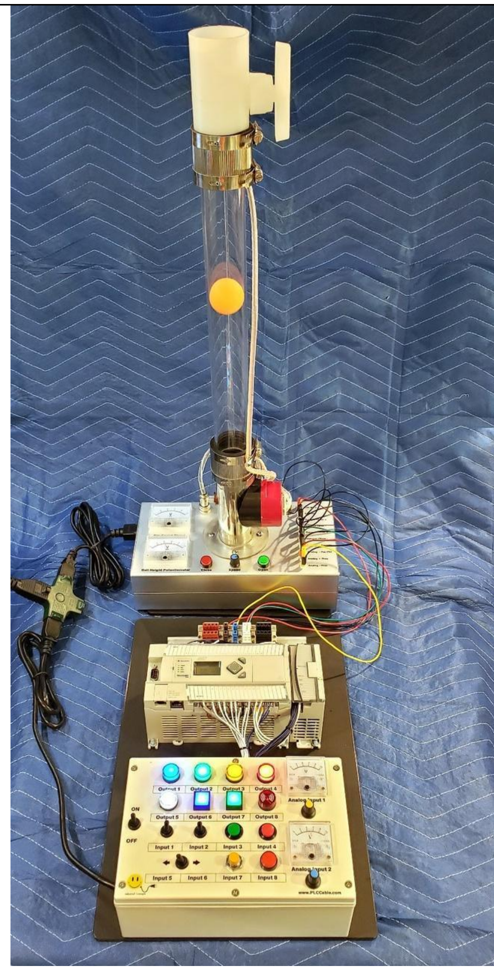
vi. What is the design concept? Describe in 1-2 sentences. (/1 point)	The design is a Portable LEARNLAB Allen Bradley PLC Trainer. It has digital and analog inputs and outputs.

vii. How is the existing design concept relevant to your design challenge? (/1 point)	This design is relevant to our design challenge because we are tasked with designing a similar PLC trainer.
viii. How does the existing concept work? Provide photos or sketches to explain how this concept works. (/1 point)	This design works by allowing students to use simple inputs/outputs to test their PLC knowledge and gain experience without needing to work on or design industry-level PLC systems. 
ix. What are pros/cons of this existing design solution? (/1 point)	This design is portable, safe, and durable. It also has digital and analog inputs and outputs. However, it only teaches how to use Allen-Bradley PLCs. It also has no HMI or additional modules.
x. Could you apply this existing design concept in your project? What are the limitations of applying this existing design concept to your design problem? Could it be adapted? (/1 points)	This design concept could be applied to this project. The portable nature of this PLC trainer would make it well suited for a lab setting. This design is limited by its lack of compatibility with outside modules. This design could be adapted to take more inputs and outputs.
xi. What is the design concept? Describe in 1-2 sentences. (/1 point)	The design concept is a miniature 3 story elevator PLC trainer. The elevator machine is controlled by a MicroLogix 1100 PLC and is designed to teach students PLC control with field devices and sensor applications.
xii. How is the existing design concept relevant to your design challenge? (/1 point)	This design concept is relevant to our design challenge because our scope is to design a PLC trainer board that

	can interact with various machine modules. Our various machine modules will teach sensor applications and PLC control just like the elevator PLC trainer.
xiii. How does the existing concept work? Provide photos or sketches to explain how this concept works. (/1 point)	 This existing concept works by having the PLC and machine as separate platforms where the machine platform has all the interactive field devices. The machine platform has sections dedicated to the connections of the elevator system. The motors, switches, and buttons are all wired to plug in boards on the front panel where students can easily find and complete connections to different devices back to the PLC.
xiv. What are pros/cons of this existing design solution? (/1 point)	The pros of this design solution are that there is an interactive machine that students can try to control while learning PLCs, the machine front panel is easy to navigate to find connections, all connections on the machine front panel are labeled for beginners to understand, and the machine components are behind an acrylic panel for visibility and safety. The cons of the existing design solution are that the interactive switches, buttons, and lights are on the machine panel as opposed to the PLC panel like an industry control panel would be, the connections to the machine panel are all labeled and setup already which doesn't allow students to learn how to create connections themselves, and that

	there is only one machine module setup for students to learn different types of PLC control.
xv. Could you apply this existing design concept in your project? What are the limitations of applying this existing design concept to your design problem? Could it be adapted? (/1 points)	We can apply some of the characteristics of the existing design concept to our project. Including all existing design concepts in our project will limit the versatility and teaching experience of our PLC trainer. For example, including set connections to the machine module like this existing design solution could limit the students experience with creating connections or different communication methods with the PLC. Things that could be adapted from this existing solution are the acrylic panels, labeled ports, various switches, and frame setup.
xvi. What is the design concept? Describe in 1-2 sentences. (/1 point)	An Arduino microcontroller is an existing solution that could be used in this application. A microcontroller is a small computer on a single integrated circuit. Like a PLC, it has a CPU, memory and programable inputs and outputs.
xvii. How is the existing design concept relevant to your design challenge? (/1 point)	In some cases, a PLC could be substituted with an Arduino microcontroller.
xviii. How does the existing concept work? Provide photos or sketches to explain how this concept works. (/1 point)	 The Arduino microcontroller takes a 5 volt supply and can supply up to 5 volts to its output pins. It's CPU and memory are contained in a single chip. It has digital pins on one side and analog pins on the other which can either be inputs or outputs.
xix. What are pros/cons of this existing design solution? (/1 point)	The pros of a microcontroller is that it's general purpose and could be used for a wider range or applications compared to a PLC. They are generally inexpensive and have a compact formfactor.

	The cons of a microcontroller is that they aren't as robust as a PLC and may be affected by the environment in an industrial setting. Microcontrollers can be more difficult to program because they use general-purpose languages rather than ladder logic or block diagrams. Microcontrollers aren't modular so addition inputs and outputs can't be added.
xx. Could you apply this existing design concept in your project? What are the limitations of applying this existing design concept to your design problem? Could it be adapted? (/1 points)	It's very unlikely that we would apply this existing design to our projects. Although a microcontroller can be used as a substitute for a PLC in many applications, student's in the ME program are already being exposed to microcontrollers and the point of this project is to expose students to something new. Additionally, PLC's are more commonly used in the industry compared to microcontrollers. This is why it's more beneficial to use a PLC rather than a microcontroller for this lab setup.
xxi. What is the design concept? Describe in 1-2 sentences. (/1 point)	The design concept is a PLC Trainer with a separate control panel platform, PLC platform, and machine module platforms that can be wired together for interaction. This concept is compatible with two different PLCs and can be modular in its machine module platform.
xxii. How is the existing design concept relevant to your design challenge? (/1 point)	This existing design concept is relevant to our design challenge because our design challenge is to create a PLC trainer platform that can interact with various modules and teach students the basics of PLC control/setup.

xxiii. How does the existing concept work? Provide photos or sketches to explain how this concept works. (/1 point)	 This existing concept works by having a control panel with open wiring that can be connected to a PLC. The machine module is already wired to a plug in board that is mounted on the module frame and the PLC can then connect to these plug ins. All power is routed from the control panel as a single source connection.
xxiv. What are pros/cons of this existing design solution? (/1 point)	The pros of this existing design solution are the ability to wire connections instead of working with pre-existing connections, use two different PLCs (brand diverse), and have the ability to be modular with machine modules. The cons of the existing design solution are multiple components/platforms to move around, hidden connections in the control panel/machine module and bad ergonomic interaction where students will need to stand and work above the platforms instead of in front of them.
xxv. Could you apply this existing design concept in your project? What are the limitations of applying this existing design concept to your	Some limitations of applying the existing design concept to our project would be the interaction with the system being up-down instead of front-back, and open wiring as a safety issue. Aspects that could be adapted are the modular

design problem? Could it be adapted? (/1 points)	nature of the PLC of choice, modular wiring capability, and machine module plug in board.

B. Translate User Needs into Engineering Design Specifications (/50 points)

1. **List user needs** (/5 points)
   Copy over your list your user needs from Assignment 1. You can add any needs you have identified since Assignment 1, ensuring that the needs in your list are numbered.

   1. Powered connections should be electronically isolated to ensure user safety
   2. Connection between theory and technical ability
   3. A simplistic trainer platform that will not scare off new users
   4. As a teaching tool, the trainer and modules must have several opportunities for students to take a look inside and explore the innerworkings safely
   5. All modules and the trainer itself must comply with industry standard regulations
   6. The ability to physically change the connections of the Inputs and Outputs on the PLC
   7. Trainer platform and modules will be easy to transport and move
   8. +-10% set point control on volumetric flow rate for wind tunnel
   9. +-10% set point control on temperature of air for wind tunnel

2. **Identify engineering metrics** (/15 points)
   Starting with your numbered list from part B.1, begin to identify suitable metrics that correspond to each need and the relevant engineering unit. Note that each need in your list should have at least one associated metric.

   Create a table similar to the table shown below. In some rare cases, you might not be able to come up with a metric that has an associated unit. (See the metric 3 in the table below as an example.) But these cases should be rare. If the metric is not self-explanatory, provide a short description of the metric and a rationale for its use. Keep this explanation concise. Although every project is different, you should expect to have somewhere between 5 and 15 metrics.

Metric #	**Customer Need #**	**Metric**	**Units**
1	6	Quantity of input and output connections	# of input and outputs
2	8	Wind tunnel flow rate	m^3/min
3	9	Wind tunnel Temperature	Deg C
4	7	PLC trainer mass	Kg
5	7	PLC trainer volume	M^3

6	1,5	Complies with industry standards (NFPA 79, 70) Complies with industry standards (NFPA 79, 70) • NFPA 79 - DC converter converts to 90-110% of nominal voltage - Electrical conductors and equipment supplied by power converters should be suitable for power characteristics identified by the manufacturer - Mounting hardware should not be used for terminating conductors used for grounding or bonding - Conductors used for grounding and bonding purposes shall be copper - Markings shall be located so as to be visible to qualified persons before examination, adjustment, servicing or maintenance of the equipment • NFPA 70 - Wiring methods should not be used for over 1000 Volts AC or 1500 Volts DC - Reconditioned lighting, dimmer and electronic control switches shall not be permitted - Switches shall be marked with the current, voltage and if horsepower rated, the max value for which they are designed - Conductors in raceways shall be continuous between outlets, boxes devices and so forth, there shall be no splice or tap within a raceway unless permitted by 300.15, 3068.56A, 376.56, 378.56, 384.56, 386.56, 388.56, or 390.56.	Binary

		- Under engineering supervision, conductor ampacities shall be permitted to be calculated by means of $I = \sqrt{\frac{Tc - Ta}{Rdc(1 + Yc)Rca}} \times 10^3$	

3. **Assign Target Specification Values** (/20 points)

Assign numerical values for each of the metrics. These values should be based on information from existing concepts (i.e. benchmarking), input from technical experts, users, and project sponsors, analysis, direct testing when possible, or relevant engineering standards (see below). At this point in your project, some of them may be best guesses. But as your project progresses, the number of "guesses" should be reduced.

Your final Specification Table should look something like the table below. It should list all metrics, the engineering unit, and the target value or range.

Below the table includes a paragraph explaining your metrics and the associated value (e.g. convince teaching team that the metrics will be a good measure of whether your design meets the required user needs).

Metric	Need	Metric	Unit	Value
1	6	Quantity of input and output connections	# of input and outputs	>= 10 inputs >= 10 outputs
2	8	Wind tunnel flow rate	m^3/min	+-10% set point control Set point: [
3	9	Wind tunnel Temperature	Deg C	+- 10% set point control Set point: [40 – 80]
4	7	PLC trainer mass	Kg	<30 kg
5	7	PLC trainer volume	M^3	<0.26 M^3
6	1,5	Complies with industry standards (NFPA 79, 70) • NFPA 79 - DC converter converts to 90-110% of nominal voltage	Binary	0 – fail 1 - pass

		- Electrical conductors and equipment supplied by power converters should be suitable for power characteristics identified by the manufacturer - Mounting hardware should not be used for terminating conductors used for grounding or bonding - Conductors used for grounding and bonding purposes shall be copper - Markings shall be located so as to be visible to qualified persons before examination, adjustment, servicing or maintenance of the equipment • NFPA 70 - Wiring methods should not be used for over 1000 Volts AC or 1500 Volts DC - Reconditioned lighting, dimmer and electronic control switches shall not be permitted - Switches shall be marked with the current, voltage and if horsepower rated, the max value for which they are designed - Conductors in raceways shall be continuous between outlets, boxes devices and so forth, there shall be no splice or tap within a raceway unless permitted by 300.15, 3068.56A, 376.56, 378.56, 384.56, 386.56, 388.56, or 390.56. - Under engineering supervision, conductor ampacities shall be permitted to be calculated by means of $I = \sqrt{\frac{Tc - Ta}{Rdc(1 + Yc)Rca}} \times 10^3$		

Green rows are performance specifications and orange rows represent constraints.

The first performance metric is the quantity of input and output connections where we aim to have a value that is greater than or equal to 10 inputs and 10 outputs. This is a good measure of our design meeting the required user needs of modular I/O connections because there will be availability of multiple connections for interaction with different field devices where commercial PLC trainer platforms fall short.
The wind tunnel will have a performance metric of meeting +-10% set point control for volumetric flow rate and temperature of air.
The fourth and fifth metric are constraining metrics where the PLC trainers' mass and volume will be constrained to a value of less than 30 kilograms and 0.26 meters cubed respectively. These were the constraints that were given to us by the project advisors and that we agreed upon as a design team. By satisfying these constraints, we will satisfy the user need for easy transportation.
The final constraining metric is metric 6 where our PLC trainer should comply with industry standards NFPA79 and NFPA70. These industry standards are for proper electrical wiring of industrial machinery and electrical safety for a workplace. The value associated with this metric is either a 0 for a failure or a 1 for a pass where our team will want to meet a value of 1 for all aspects of electrical components. This metric will satisfy the user need of safety where we can eliminate the dangers of electrical failures/interactions with the user.

4. **Identify Relevant Standards** (/10 points)
   Identify one or two standards that are relevant for your project. Provide a link to the standards and a short paragraph explaining what the standard is and why it is applicable to your project. As discussed in class, standards may impose constraints and thus may need to be incorporated into the specifications table. However, they may describe testing procedures, quality or safety standards, etc. which may not directly affect a specification. If the standard does affect a specification, note which specification(s) it affects.

NFPA 79:

https://www.nfpa.org/codes-and-standards/nfpa-79-standard-development/79

*(Must have an account to access)

This code aims to provide the standards for the implementation of electrical equipment and apparatus in industrial machines for the protection and safety of life and property. This standard applies to all systems that operate under 1000 volts and specifically standardizes connection/disconnection means, grounding, circuits, operator interfaces, wiring and equipment. This standard will be applicable to our project because we will need to follow the industry standards for operator interfaces, wiring, enclosures, connection/disconnection and locality of equipment to ensure our PLC trainer complies with the protection and safety of life and property.

NFPA 70:

https://www.nfpa.org/codes-and-standards/nfpa-70-standard-development/70

*(Must have an account to access)

This code aims to provide general safe practice that come with the inherent risks that come with working with electricity. Specifically, it covers safe practices for installing and removing electrical conductors, equipment, and raceways; as well as signaling and communication conductors, equipment, and raceways. This will affect how we can wire things together, like the induction motor to the VFD to the PLC for example. This could constraints such as the volume and the weight, adding or taking away conductors in our overall design.