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Interactive Case Studies for Designing Automated Systems for Discrete, Continuous, and Hybrid Industrial Processes

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Abstract

Research suggests that the inclusion of case studies in courses helps make engineering concepts more realistic and relevant for learners. In the area of automated manufacturing system design, case studies can help convey the steps involved in designing systems to automate industrial processes. Interviews with automated system integrators have shown that they often recall other systems they have seen or worked on previously (i.e., cases) when designing new systems. However, the actual design process is complex, and the designs tend to be closely guarded, proprietary information. Therefore, the availability of case studies for industry automated system design is limited, especially case studies that illustrate the control logic behind the steps of an automated manufacturing process.

This paper describes the development of three interactive animated case studies related to the design of systems that automate manufacturing processes. The objectives are to (1) cover the three major types of manufacturing processes (discrete, continuous, and hybrid); (2) provide a broadly accessible and systematic sequence for designing and developing an integrated automated system design solution; and (3) integrate previously learned concepts—such as manufacturing processes, instrumentation and control, and automation and robotics—in capstone-like project design. The case studies illustrate the design of automated lines for each type of process—discrete (engine block), continuous (iron bar), and hybrid (chocolate).

Each case study includes a problem statement, system setup, and a case analysis. The system setup section provides a verbal description and an animated illustration of the system operation. The case analysis includes a description of the inputs and outputs, assignment of programmable logic controller (PLC) I/O ports for each input and output, sequence of events, PLC ladder logic program, and an animated schematic illustrating each step of the wiring process needed to interface the various hardware components. At the end of the case analysis section, learners have an opportunity to practice interfacing the system components.

Survey results suggest that the case studies helped learners to understand how to translate a manufacturing process into control logic and enhanced their interest in industrial automation and control.

1 Introduction

Automation has a profound impact on our daily lives. Automated systems produce the things we eat, the clothes we wear, and the vehicles we ride in. Designing, building, and servicing automated systems is a challenging task. It requires multi-faceted knowledge of hardware, software, and how to interface components such as sensory devices and controllers. Students often lack a system level perspective of automated systems and how each component contributes to a system [1]. Over the years, researchers have been looking at this challenge and addressing this from different perspectives. Hsieh [2-3] developed web-based conceptual design environments to allow **application engineers** to develop a concept design proposal of an automated assembly line or robotic work-cell system based on the production quantity requirements from the customers. The environments guide users in a systematic way to translate the requirements into engineering design in assembly line and robotic cell. Chen [4] and Kelly [5] suggest that using **case studies** in engineering education shifts the learning process from passive absorption of theory to active application in real-world contexts. Case studies impact the "affective" (attitudinal) and "higher-order thinking" domains of learning; they are critical thinking, realism and relevance. Hsi and Agogino [6] also suggest that the use of case studies for learning engineering design has a positive impact on generating excitement about engineering, conveying industry "best" practices, and demonstrating the design process. Hsieh [7] has noted that automated system integrators often recall other systems they have seen or worked on previously in coming up with conceptual designs. Hsieh [8] presents the ASI Tutor , a web based interactive animation environment to allow users to learn about PLC programming, I/O interface, and automated system design via case studies that utilize a systematic approach to translating manufacturing operations into I/O device assignments, interfacing with a controller, and control logic design all in one virtual web based environment. In this paper, we describe the design and evaluation of **case studies for discrete, continuous, and hybrid** industrial processes.

2 Methodology

Automated manufacturing processes can be categorized into three broad types: discrete, continuous, and hybrid. Hybrid processes include both discrete and continuous elements. Industry case studies were created to illustrate the design of automated lines for each type of process—discrete (engine block), continuous (iron bar), and hybrid (chocolate).

Each case study includes a problem statement, system setup, and a case analysis. The system setup section provides a verbal description and an animated illustration of the system operation. The case analysis includes a description of the inputs and outputs, assignment of programmable logic controller (PLC) I/O ports for each input and output, sequence of events, PLC ladder logic program, and an animated schematic illustrating each step of the wiring process needed to interface the various hardware components. At the end of the case analysis section, learners have an opportunity to practice interfacing the system components.

3 Case study: Engine block manufacturing (Discrete process)

Engine block manufacturing is an example of a discrete process. Below are descriptions and illustrative screenshots of each component of the case study. The full case study is at: https://people.tamu.edu/~hsieh/ASI-Tutor/case-study/#/2

3.1 Problem statement

The first screen (Fig. 1) of the Problem Statement section provides background information about engine block manufacturing.

The second screen (Fig. 2) presents an overall view of the system layout. In this case study, the automated line has two stages. Stage 1 is melting and molding. Stage 2 is grinding and drilling.

The next two screens describe the power rating requirements and PLC port assignments for each I/O device involved in Stage 1 (Fig. 3) and Stage 2 (Fig. 4).

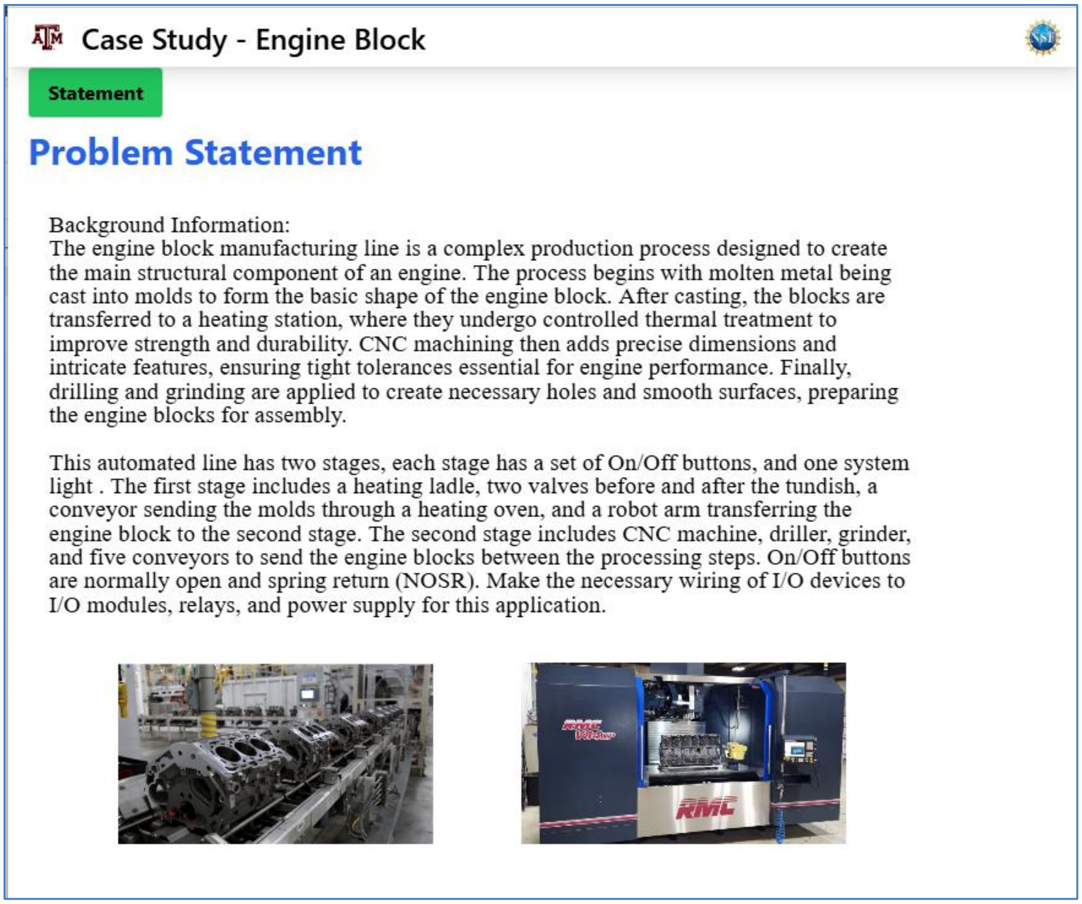


Fig.1. Background information screen from Problem Statement of Engine Block Case Study.

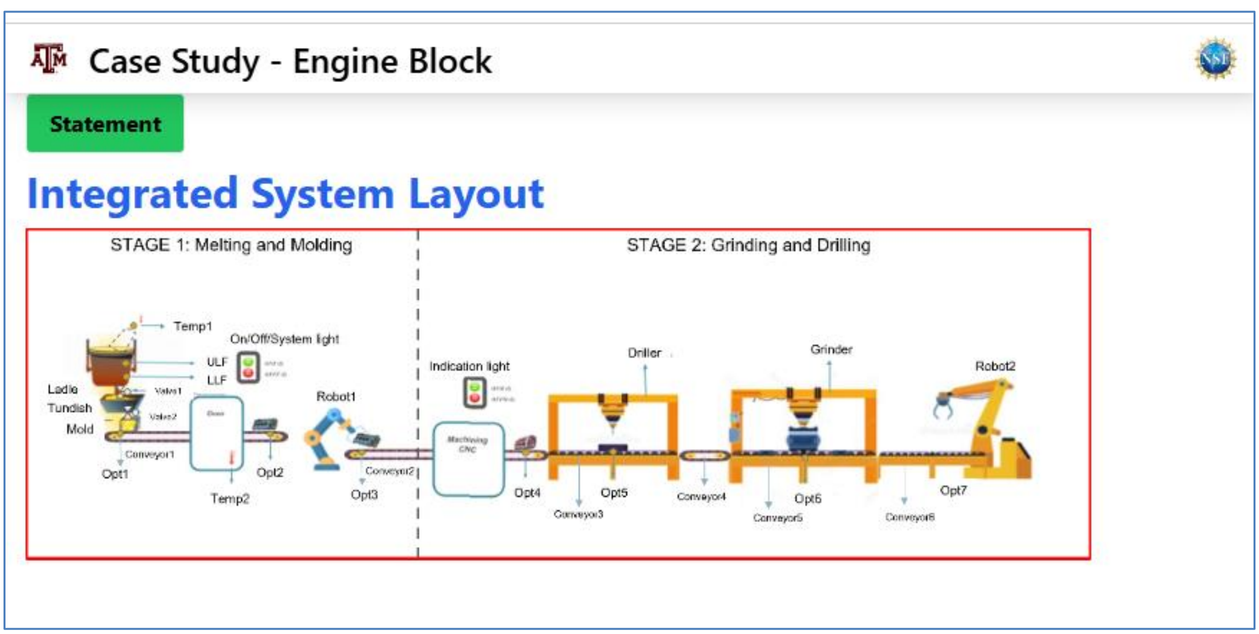


Fig.2. System Layout screen from Problem Statement of Engine Block Case Study.

Case Study - Engine Block

Statement

Problem Statement

Stage 1: Melting and Molding

The power rating requirements and I/O port assignments for each I/O device are as follows.

Input	Address	Voltage	Output	Address	Voltage
ON	IN0	24VDC	System Light (L)	OUT0	24VDC
OFF	IN1	24VDC	Pump (P)	OUT1	230VDC
TSenor1(S)	IN3	24VDC	Ladle (La)	OUT2	400VDC
ULF	IN2	24VDC	Valve1 (V1)	OUT3	24VDC
LLF	IN5	24VDC	Valve2 (V2)	OUT4	24VDC
Opt1	IN4	24VDC	Conveyor1 (C1)	OUT5	230VDC
Opt2	IN7	24VDC	Oven(O)	OUT6	400VDC
TSensor2(T)	IN6	24VDC	Robot 1(DI1)	OUT7	24VDC
Robot 1(DO1)	IN10	24VDC			
Where, ULF, LLF are proximity sensors to check liquid level withing the tank, and Tsensor1 is a simple setpoint while Tsensor2 is a thermocouple. Most of the I/O points are 24VDC except the Pump, Ladle, Conveyor, and Oven have AC required voltages.					

Two I/O modules—1756 IB16 and 1756 OB8—are available for this application. Three relays and two power supplies are also available.

Fig. 3. Power rating requirements and I/O port assignments for Stage 1, Melting and Molding

Case Study - Engine Block

Statement

Problem Statement

Stage 2: Grinding and Drilling

The power rating requirements and I/O port assignments for each I/O device are as follows.

Input	Address	Voltage	Output	Address	Voltage
ON	IN0	24VDC	Robot 2(DI1)	#1-OUT0	24VDC
OFF	IN1	24VDC	CNC-Out1 (IN0)	#1-OUT2	400VAC
Robot 2(DO1)	IN2	24VDC	Driller-Out1 (IN0)	#1-OUT4	400VAC
Opt3	IN3	24VDC	Grinder-Out1 (IN0)	#1-OUT7	400VAC
Opt4	IN4	24VDC			
Opt5	IN5	24VDC	System Light (L)	#2-OUT0	24VDC
Opt6	IN6	24VDC	Conveyor2 (C2)	#2-OUT1	230VAC
Opt7	IN7	24VDC	Conveyor3 (C3)	#2-OUT3	230VAC
Opt8	IN8	24VDC	Conveyor4 (C4)	#2-OUT5	230VAC
			Conveyor5 (C5)	#2-OUT6	230VAC
			Conveyor6 (C6)	#2-OUT8	230VAC
Where, optical sensors are used to check the object presence. All inputs are 24VDC and most of the outputs have AC required voltages. Slot 7 is used as a second PLC output module.					

Two I/O modules—1756 IB16 and 1756 OB8—are available for this application. Three relays and two power supplies are also available.

Fig. 4. Power rating requirements and I/O port assignments for Stage 2, Grinding and Drilling

3.2 Setup

The Setup section includes a verbal description and an animated illustration of the engine block manufacturing line operation.

The first page (Fig. 5) of the Setup section provides a verbal description of the steps involved in Stage 1 of the manufacturing process (Melting and Molding).

The second page animates the steps in Stage 1. Users click the On button to start the animation. Text descriptions are synced with each step of the animation. For example, in the screenshot in Fig 6, the text description states that “After valve 1 operates for 5 seconds, and the mold presents at Opt1, Valve2 is energized.”

Figs. 7 and 8 provide similar information for Stage 2 (Grinding and Drilling).

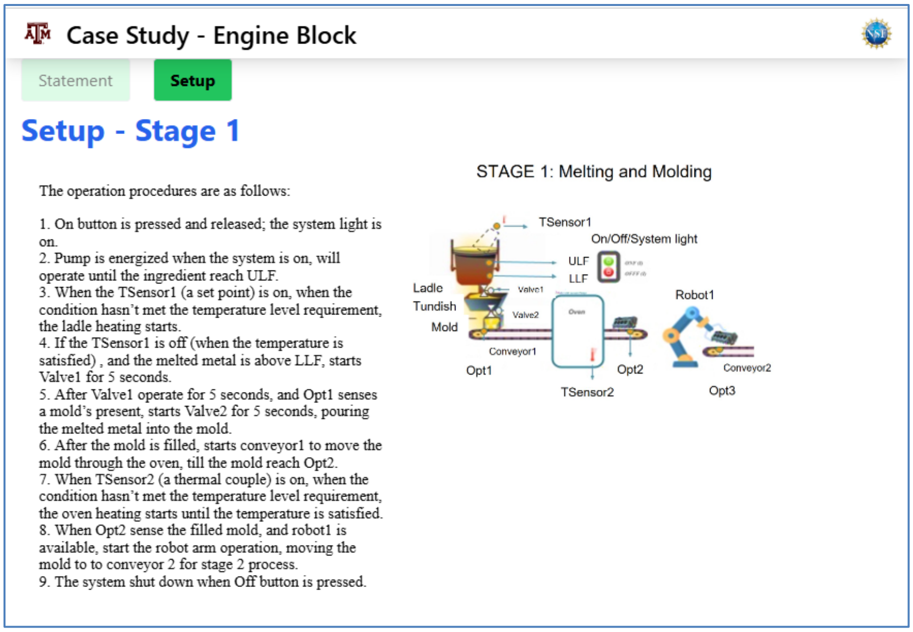


Fig. 5. Steps involved in Stage 1 of the manufacturing process (Melting and Molding).

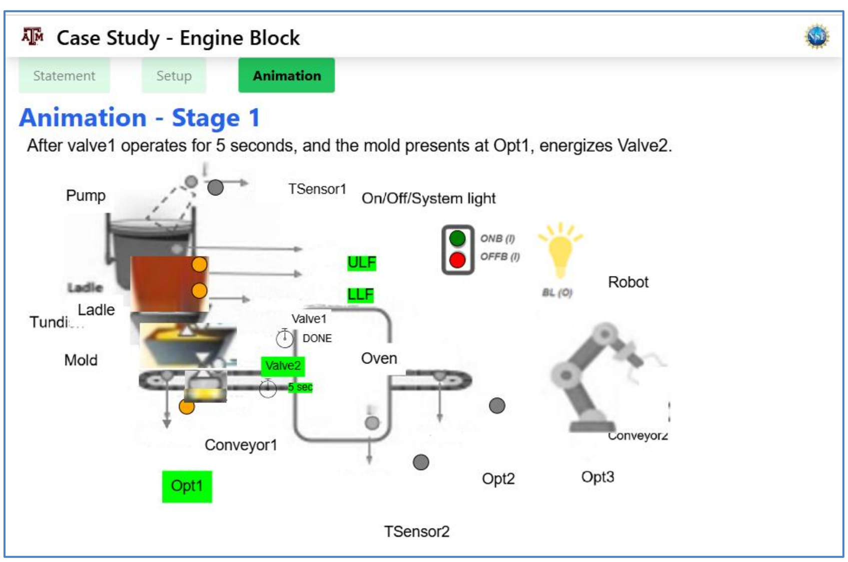


Fig. 6. Animation of steps involved in Stage 1 of the manufacturing process (Melting and Molding).

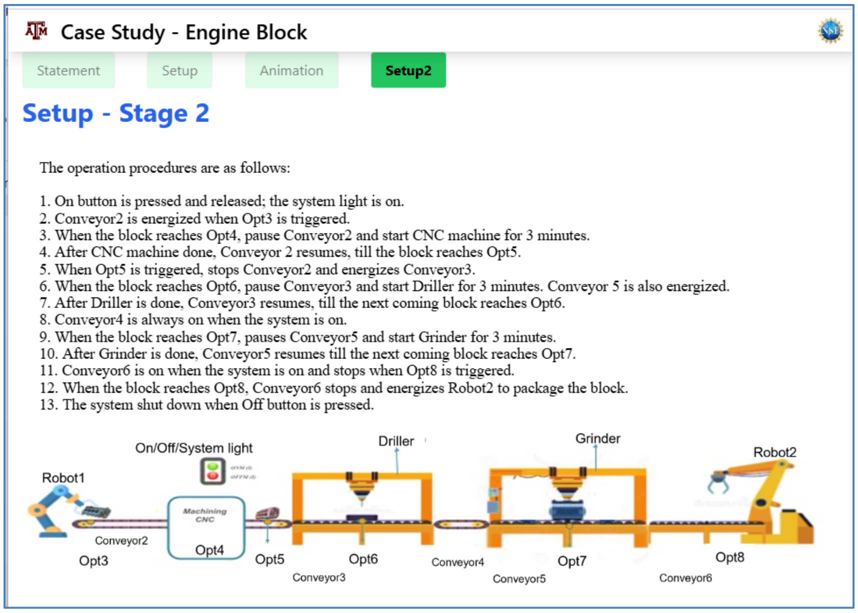


Fig. 7. Steps involved in Stage 2 of the manufacturing process (Grinding and Drilling).

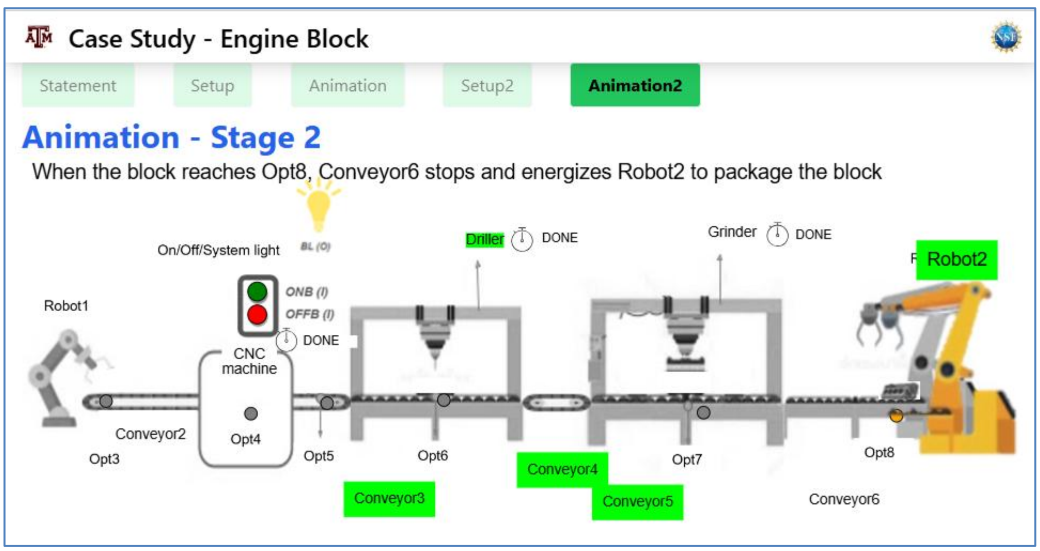


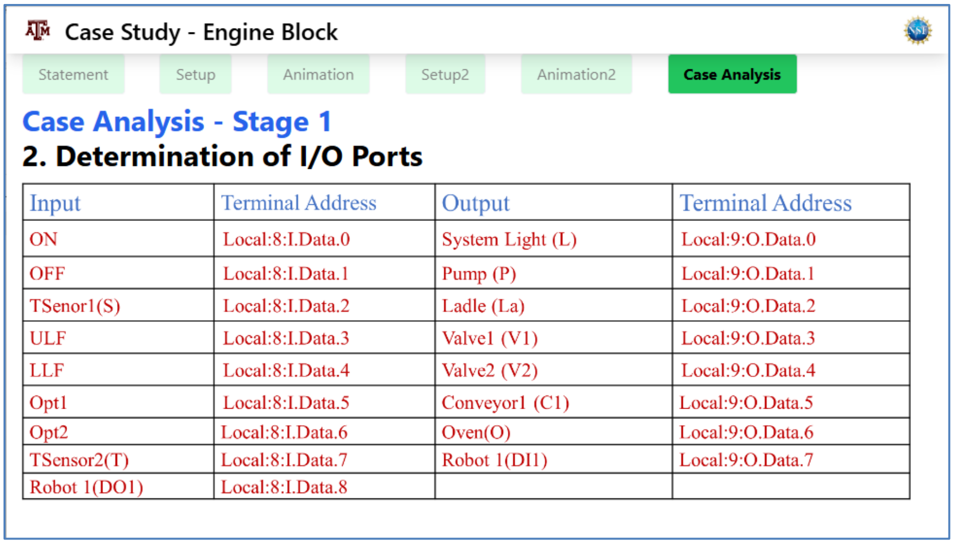
Fig. 8. Animation of steps involved in Stage 2 of the manufacturing process (Grinding and Drilling).

3.3 Case Analysis

The case analysis section includes a description of the inputs and outputs for both stages of the engine block manufacturing process, determination of programmable logic controller (PLC) I/O ports for each input and output, sequence of events, PLC ladder logic program, an animated schematic illustrating each step of the wiring process needed to interface the various hardware components. At the end of the case analysis section, learners have an opportunity to practice interfacing the system components.

3.3.1 Inputs and Outputs and Determination of I/O Ports

Fig. 10 shows the I/O port assignments for each input and output in Stage 1 of the engine block manufacturing process.



Case Study - Engine Block

Statement | Setup | Animation | Setup2 | Animation2 | Case Analysis

Case Analysis - Stage 1

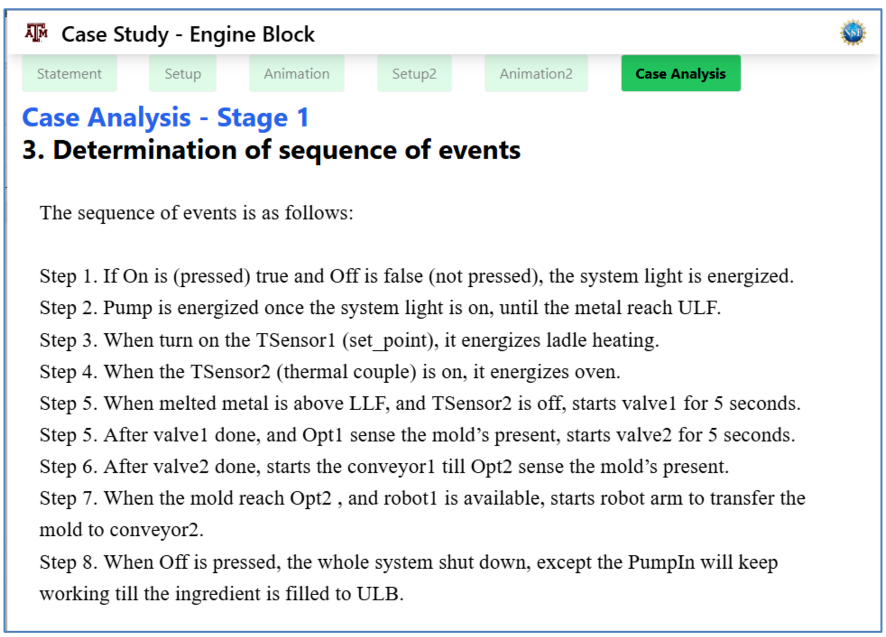
2. Determination of I/O Ports

Input	Terminal Address	Output	Terminal Address
ON	Local:8:I.Data.0	System Light (L)	Local:9:O.Data.0
OFF	Local:8:I.Data.1	Pump (P)	Local:9:O.Data.1
TSenor1(S)	Local:8:I.Data.2	Ladle (La)	Local:9:O.Data.2
ULF	Local:8:I.Data.3	Valve1 (V1)	Local:9:O.Data.3
LLF	Local:8:I.Data.4	Valve2 (V2)	Local:9:O.Data.4
Opt1	Local:8:I.Data.5	Conveyor1 (C1)	Local:9:O.Data.5
Opt2	Local:8:I.Data.6	Oven(O)	Local:9:O.Data.6
TSensor2(T)	Local:8:I.Data.7	Robot 1(DI1)	Local:9:O.Data.7
Robot 1(DO1)	Local:8:I.Data.8		

Fig. 10. I/O port assignments for each input and output in Stage 1.

3.3.2 Determination of Sequence of Events

Fig. 11 shows the sequence of events in Stage 1 from a controller perspective.



Case Study - Engine Block

Statement | Setup | Animation | Setup2 | Animation2 | Case Analysis

Case Analysis - Stage 1

3. Determination of sequence of events

The sequence of events is as follows:

Step 1. If On is (pressed) true and Off is false (not pressed), the system light is energized.
Step 2. Pump is energized once the system light is on, until the metal reach ULF.
Step 3. When turn on the TSensor1 (set_point), it energizes ladle heating.
Step 4. When the TSensor2 (thermal couple) is on, it energizes oven.
Step 5. When melted metal is above LLF, and TSensor2 is off, starts valve1 for 5 seconds.
Step 5. After valve1 done, and Opt1 sense the mold's present, starts valve2 for 5 seconds.
Step 6. After valve2 done, starts the conveyor1 till Opt2 sense the mold's present.
Step 7. When the mold reach Opt2 , and robot1 is available, starts robot arm to transfer the mold to conveyor2.
Step 8. When Off is pressed, the whole system shut down, except the PumpIn will keep working till the ingredient is filled to ULB.

Fig. 11. Sequence of events in Stage 1 from a controller perspective.

3.3.3 Problem Solution – Ladder Logic

The Problem Solution screens show and explain each rung of the PLC ladder logic program that needs to be developed to control the manufacturing process. Fig. 12 shows the first rung of the program for Stage 1 of the engine block manufacturing process (Melting and Molding). Figure 13 shows a section of the ladder logic program used to control Stage 2 of the process (Grinding and Drilling).

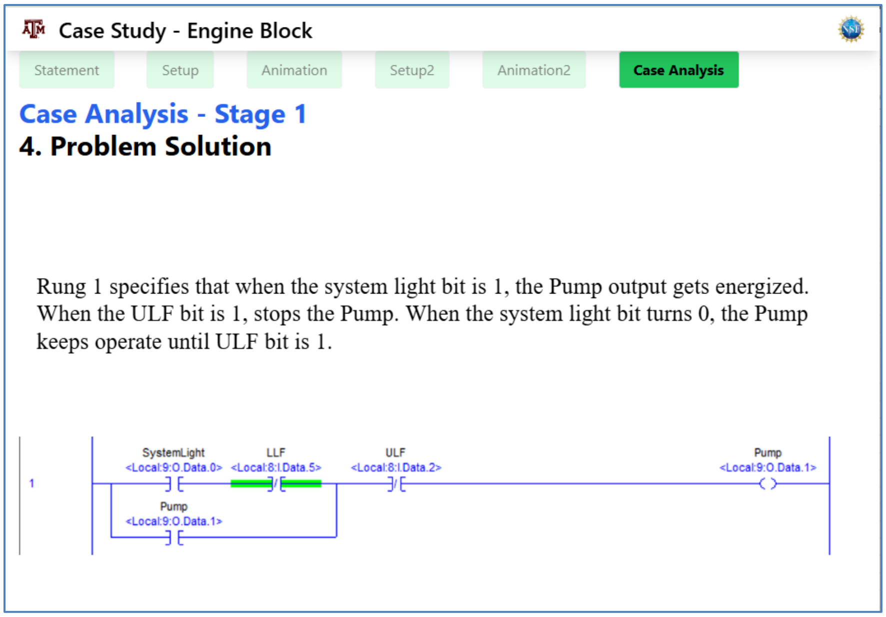


Fig. 12. First rung of ladder logic program to control Stage 1 (Melting and Molding).

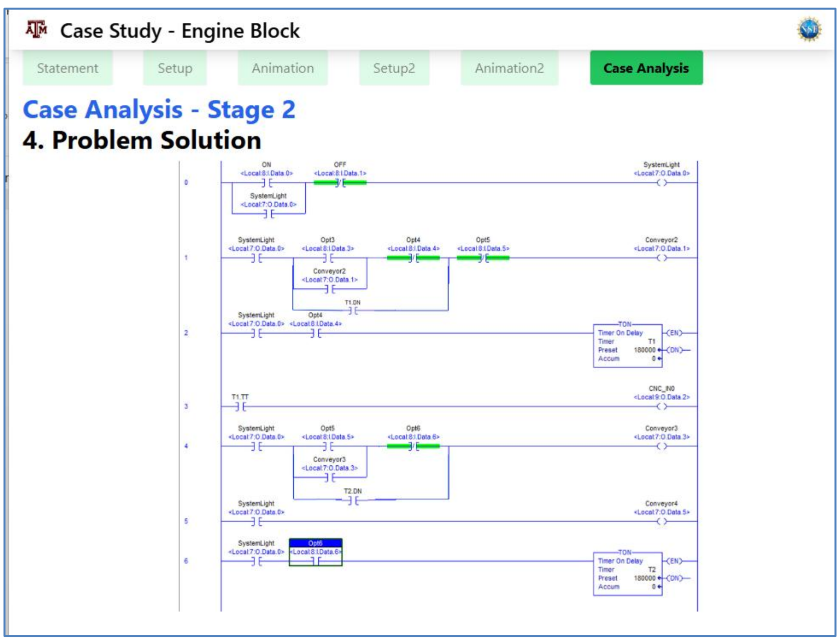


Fig. 13. Section of the ladder logic program used to control Stage 2 (Grinding and Drilling).

3.3.4 Schematic

The Schematic section of the Case Analysis provides a step-by-step animated illustration of the wiring process needed to interface the various hardware components. For example, Fig. 14 shows the 18th step (out of 62) of the interfacing process for Stage 1. Fig. 15 shows the complete schematic for Stage 1. Fig. 16 shows the complete schematic for Stage 2, which has 72 steps.

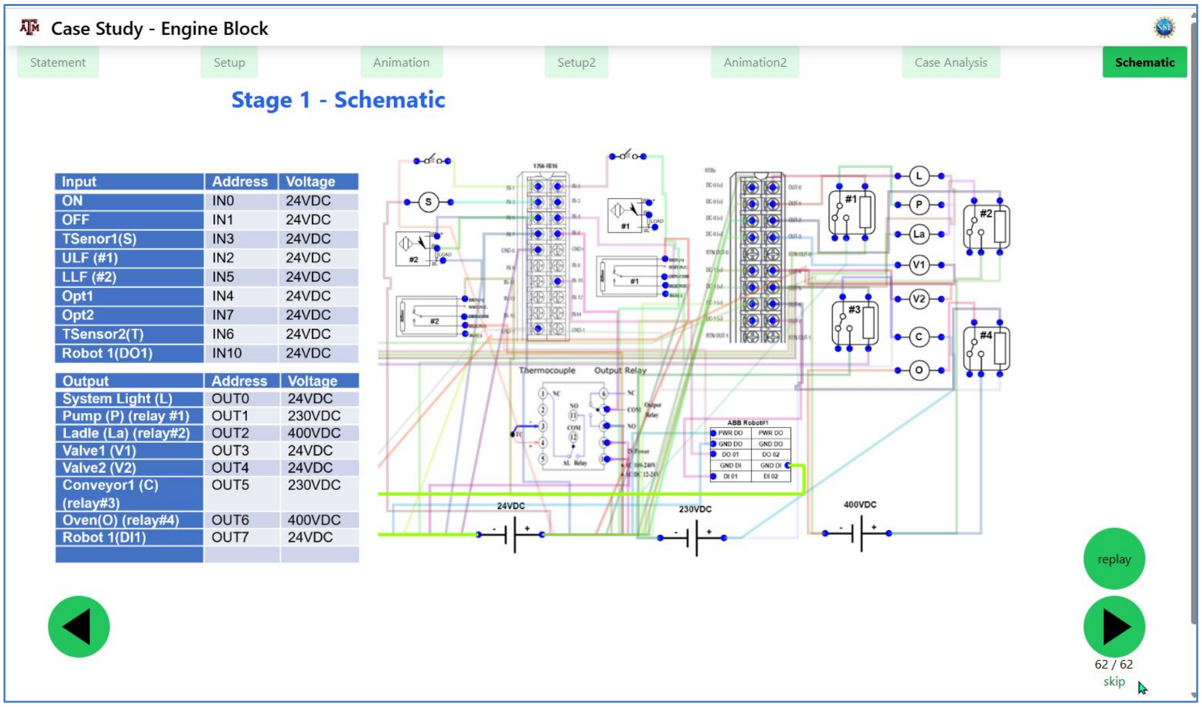


Fig. 14. Complete schematic for Stage 1.

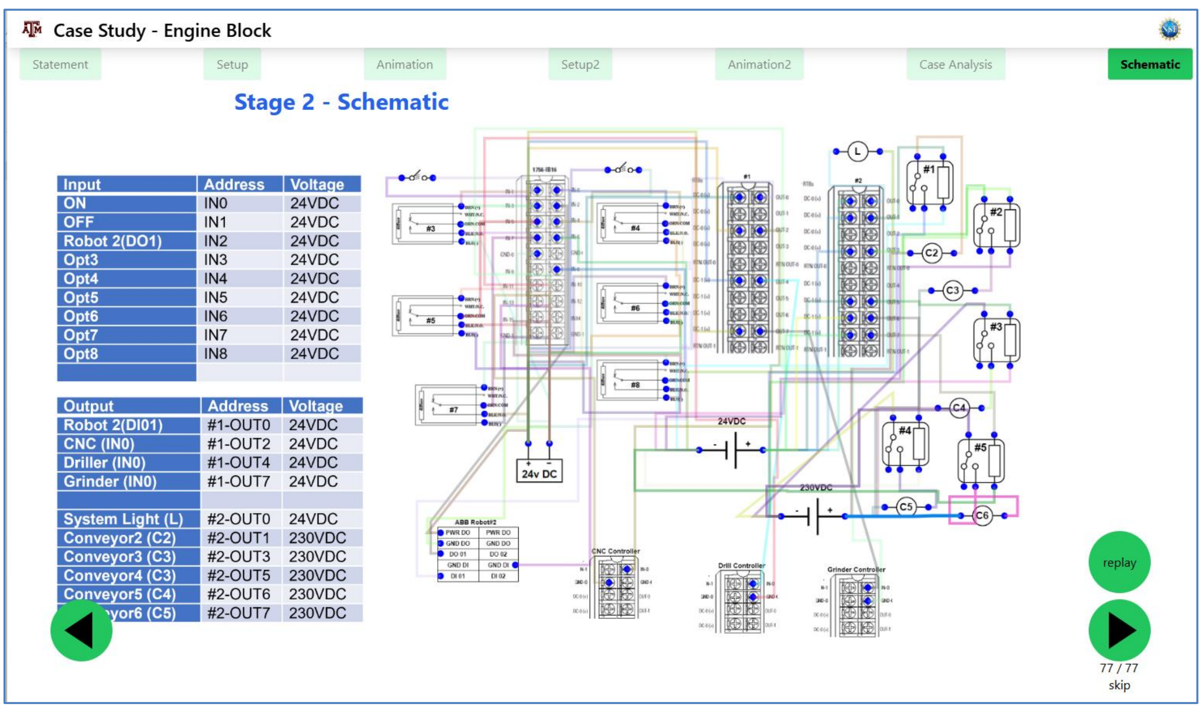


Fig. 15. Complete schematic for Stage 2.

3.3.5 Interface Practice

At the end of the case analysis section, learners have an opportunity to practice interfacing the system components. Figure 16 shows the user interface for the Stage 1 interface practice screens, respectively.

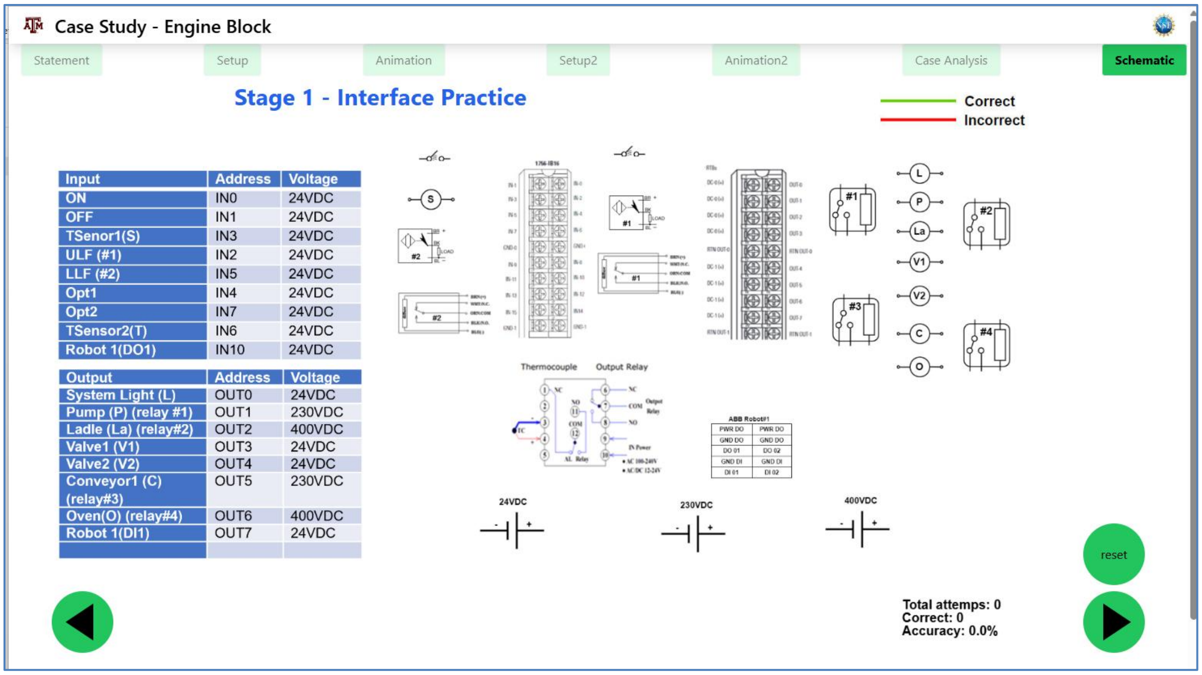


Fig. 16. User interface for Stage 1 practice

4 Case studies: Iron bar manufacturing (Continuous process) and Chocolate (Hybrid process)

Iron bar manufacturing is an example of a continuous process. Below are descriptions and illustrative screenshots of the problem statement and system layout. The full case study is at: https://people.tamu.edu/~hsieh/ASI-Tutor/case-study/#/3

4.1 Problem statement

The first screen (Fig. 18) of the Problem Statement section provides background information about iron bar manufacturing. The second screen (Fig. 19) presents an overall view of the system layout. Like the engine block manufacturing line in the case study for discrete processes, the automated line for iron bar manufacturing has two stages. Stage 1 is Melting, Molding, and Roughing. Stage 2 is Finishing and Laser Cut.

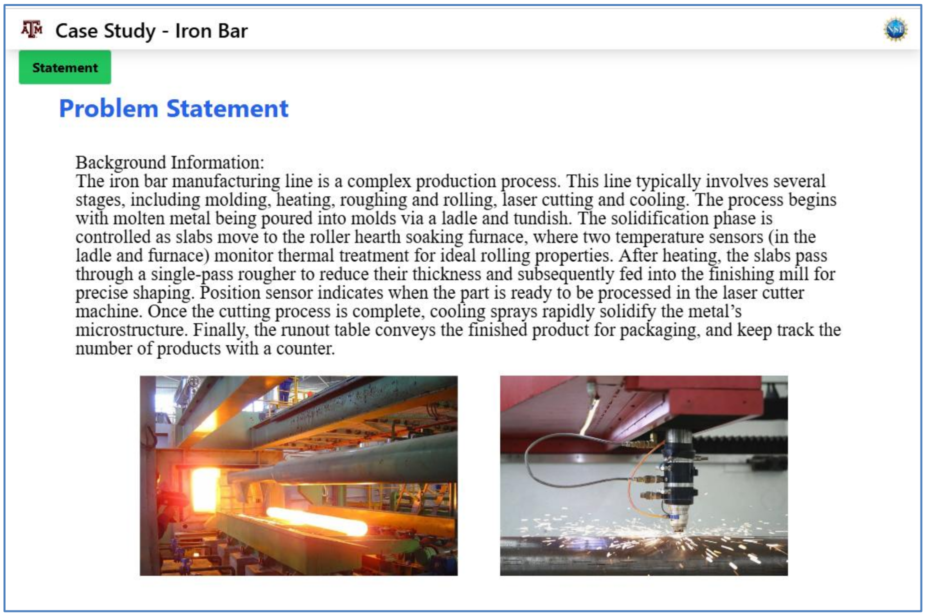


Fig. 18. Background information screen from Problem Statement of Iron Bar Case Study.

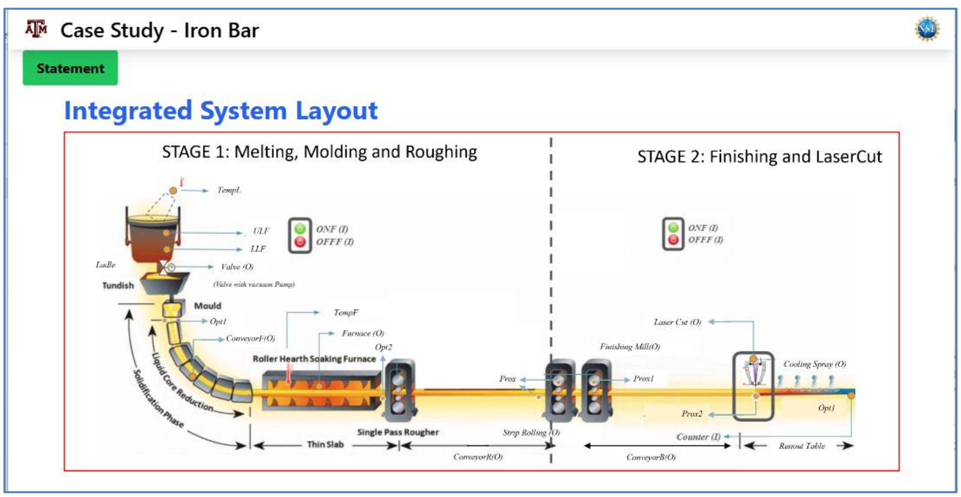


Fig. 19. System Layout screen from Problem Statement of Iron Bar Case Study.

5 Case study: Chocolate manufacturing (Hybrid process)

Chocolate manufacturing is an example of a hybrid process. Below are descriptions and illustrative screenshots of the problem statement and system layout. The full case study is at: https://people.tamu.edu/~hsieh/ASI-Tutor/case-study/#/1

5.1 Problem statement

The first screen (Fig. 20) of the Problem Statement section provides background information about iron bar manufacturing. The second screen (Fig. 21) presents an overall view of the system layout. The automated line for chocolate manufacturing has three stages. Stage 1 is Refining and Mixing. Stage 2 is Molding and Cooling. Stage 3 is packing.

The next three screens describe the power rating requirements and PLC port assignments for each I/O device involved in Stages 1, 2, and 3. These screens look similar to Figs. 3 and 4 above.

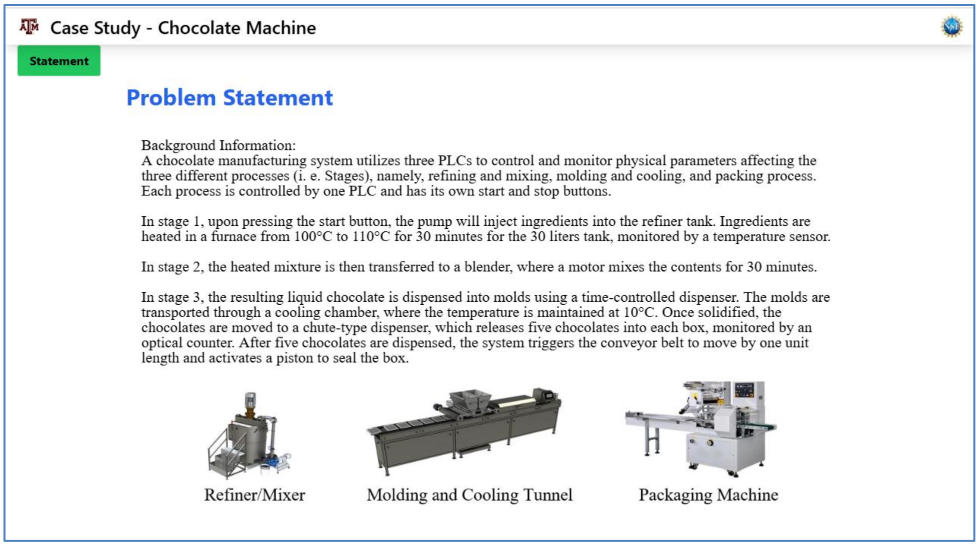


Fig. 20. Background information screen from Problem Statement of Chocolate Case Study.

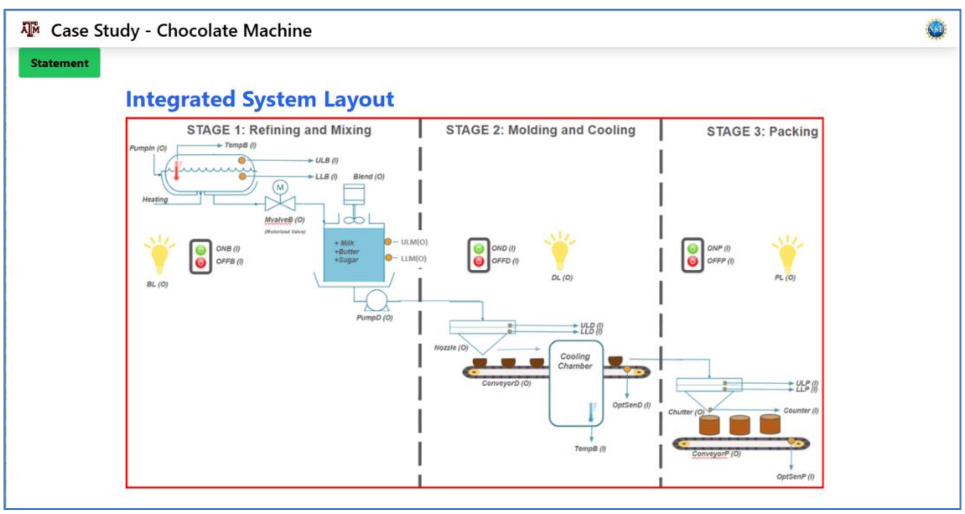


Fig. 21. System Layout screen from Problem Statement of Chocolate Case Study.

6 Evaluation

6.1 Participants and objectives

The case studies were evaluated by 60 undergraduate students in Fall 2025. The evaluation was conducted during the lab time late in the semester after the students learned about PLC programming, actuators, sensor technology, industrial robot and I/O interfacing. Because all the three case studies, continuous (iron bar), discrete (engine block), and hybrid (chocolate) process are very complex manufacturing processes required multiple and dedicated machinery, and multiple production lines to make the final products. The goal of the evaluation was to collect feedback about the case study design.

All the students reviewed the case studies and 9 of them opted to participate in an opinion survey (participation rate = 86.9%). The survey asked participants to indicate their level of agreement with the following statements using a 5-point Likert scale.

- The animation of the case study helped me visualize how the widget packaging process works.
- The animation of the case study helped me visualize how the products are produced.
- The case study was easy to understand.
- The schematic and interface practice helped me understand how to interface the components of an automated system.
- I would like more case studies like this one to help me learn how to automate a process.
- The case study was relevant to my education.

Survey participants also had the opportunity to answer two open-response questions.

- The most helpful thing about this case study was: ___________
- The case study could be improved if: ____________

6.2 Results

Figure 22 shows the average ratings in response to each question listed above for the Iron Bar case study. The results suggest that students enjoyed every aspect of the design (all above 4.0 out of 5). They felt the work is very relevant and would like to see more case studies created (4.48 highest).

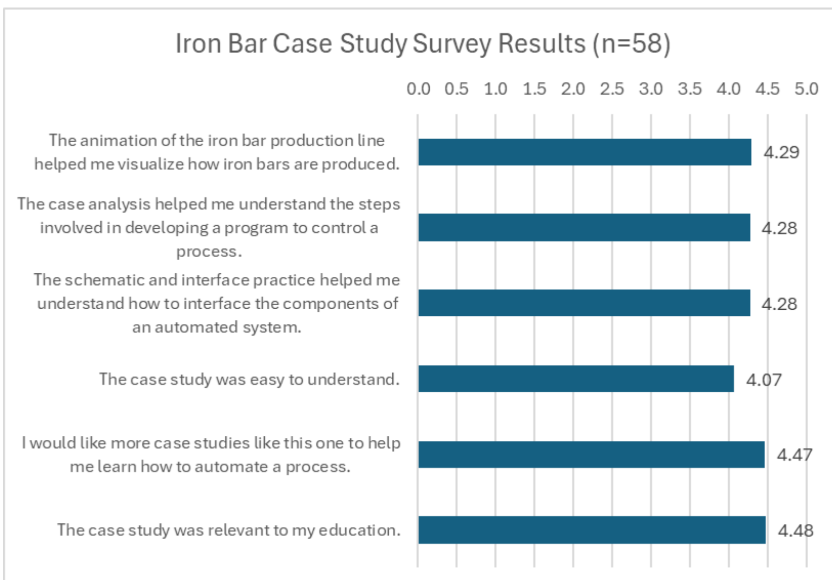


Figure 22. Iron Bar Case Study Evaluation Results

Figure 23 shows the average ratings in response to each question listed above for the Engine Block case study. The results suggest that students enjoyed every aspect of the design (all above 4.27 out of 5). They felt the work is very relevant and would like to see more case studies created (4.53 - highest).

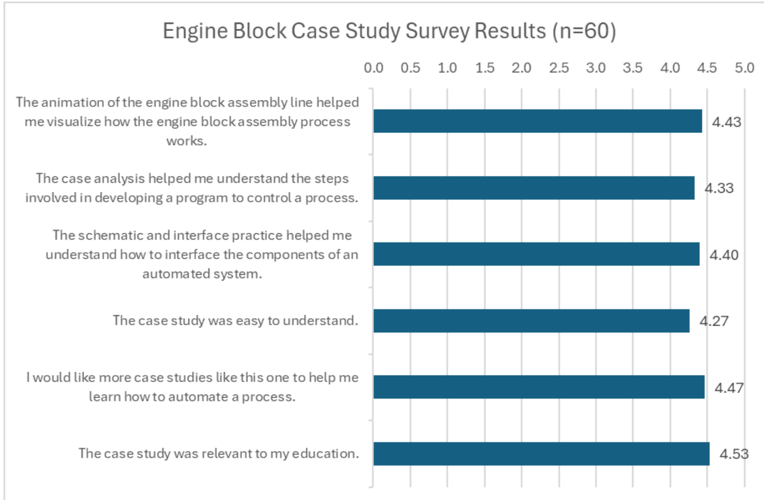


Figure 23. Engine Block case Study Evaluation Results

Figure 24 shows the average ratings in response to each question listed above for the Chocolate Candy case study. The results suggest that students enjoyed every aspect of the design (all above 4.01 out of 5). They felt the work is very relevant and would like to see more case studies created (4.70 - highest).

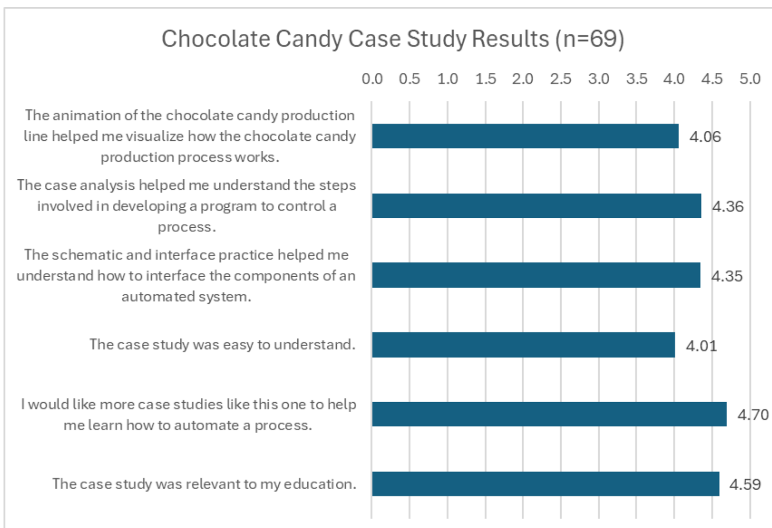


Figure 24. Chocolate Case Study Evaluation Results

7 Adoption and Lesson Plans

The case studies are designed to (1) cover three major manufacturing processes (discrete, continuous, and hybrid); (2) provide a broadly accessible and systematic sequence for designing and developing an integrated automated system design solution given manufacturing sequence, I/O devices and controller, and control logic design to interface I/O with system controller; and (3)) integrate previously learned concepts—such as manufacturing processes, instrumentation and control, and automation and robotics—in capstone-like project design. These case studies could be used for courses that cover sensors and instrumentation, manufacturing processes, automated system design, and sensor design that involve building an automated system. Following are potential adoption strategies and courses.

- How do furnace and metal melting processes work? How can you design an automated system to do this? How would you control it? (Manufacturing Processes; Capstone Project)
- How do sensors such as optical switches work? How can they be used in an industry setting? How would you interface them with an industrial controller? When would you interface a I/O device with a relay? (Sensors and Quality Control; Instrumentation and PLC; Automation and Robotics)
- How can an integrated solution be designed and developed to automate a real-life process? (Capstone Project)

8 Conclusion

In this paper, we present three interactive animation-based case studies to guide students to design an industrial scale automated system for discrete (Engine Block), continuous (Iron Bar), and hybrid (Chocolate) processes. Steps covered include problem formulation, I/O device identification, assigning I/O ports to controllers, composing the control logic program to synchronize the manufacturing operations, and interfacing I/O devices to controllers. These are all essential skills for control engineers in industry. The work was evaluated by 60 upper-level engineering technology students with favorable ratings. Future work includes (1) using pre- and post-tests to evaluate learning outcomes when teaching topics such as sensor technologies, PLC programming, and I/O interfacing; and (2) designing a low-cost tool and algorithm to investigate the cognitive load of learners as they learn how to design automated systems and to provide appropriate, just-in-time interventions to help make the learning experience more effective and efficient.

9 Acknowledgement

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