AC 2010-510: CASE STUDIES FOR LEARNING AUTOMATED SYSTEM INTEGRATION

Sheng-Jen Hsieh, Texas A&M University

Dr. Sheng-Jen ("Tony") Hsieh is an Associate Professor in the Dwight Look College of Engineering at Texas A&M University. He holds a joint appointment with the Department of Engineering Technology and the Department of Mechanical Engineering. His research interests include engineering education, cognitive task analysis, automation, robotics and control, intelligent manufacturing system design, and micro/nano manufacturing. He is also the Director of the Rockwell Automation laboratory at Texas A&M University, a state-of-the-art facility for education and research in the areas of automation, control, and automated system integration.

Case Studies for Learning Automated System Integration

Abstract

Research indicates 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. In addition, exposure to relevant cases can help in problem-solving and automated system design. Interviews with automated system integrators have shown that they often recall other systems they have seen or worked on previously—that is, cases—in coming up with conceptual designs.

This paper will describe the development of case studies to help students to learn the automated system design process. The case studies are based on examples from industry and illustrate good industrial design practice. Each case study walks learners through the stages of coming up with a conceptual design, including: 1) identify requirements; 2) collect data; 3) determine product assembly sequence and cycle time; 4) determine equipment required for assembly process; 5) determine layout of assembly line; and 6) perform cost estimation and analysis

Motive

Automation has a profound effect on the way we do work. A U.S. Census Bureau report notes that yearly exports in the flexible manufacturing category (equivalent to industrial automation) were $19.44B in 2006, a 10% jump from $17.61B in 2005[1]. Moreover, monthly exports in the flexible manufacturing category were $4.06B in March 2008, a 0.5% jump from $4.04B in March 2007[2]. This trend is likely to continue to increase as the manufacturing sector continues to transform to a high tech, less labor-intensive and value added industry using advanced automated systems.

Integrating the components of an automated manufacturing system requires knowledge about the various mechanical and electrical devices available to make up the system—including their functions, power requirements, and specific characteristics—and the ability to write PLC programs to orchestrate and synchronize the process being automated. It is a complex cognitive skill, and often there is no course available that teaches it. In addition, some colleges do not have the equipment resources needed to provide hands-on experience with automated systems. Consequently, new automation and control engineers are often not fully prepared to perform system integration tasks. Needed are readily available instructional materials that can better prepare new engineers for these challenging tasks.

A study by Hsi and Agogino[3] suggests 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[4] has noted that automated system integrators often recall other systems they have seen or worked on previously (i.e., cases) in coming up with conceptual designs. Although there are quite a few programs that depict manufacturing processes (notably the cable TV show "Made in America"), there are relatively few instructional materials that systematically walk learners through the process of designing an automated system. In this paper, we present the process of the developing such a case study and illustrate the principles with a real-life example.

Case Study Development Process

Over 40 engineers at system integration companies in the U.S. and Europe were interviewed and asked to describe how they would go about designing a new automated manufacturing system. The interviews were transcribed and analyzed. The results and theoretical work were evaluated to come up with a generalized process for automated system design. This process was used to guide the case study development. Steps include:

1. Identify requirements.
2. Collect data.
3. Determine assembly sequence and cycle time.
4. Select assembly line components.
5. Determine layout of assembly line.
6. Perform cost estimation and analysis.

This process described in detail in the following sections and illustrated with screen shots from a case study on how to design an automated system for crayon manufacturing. The actual case study can be found at: http://etidweb.tamu.edu/hsieh/Autosys/flash/Case_studies_learning.html

1. Identify requirements

Often the customer will provide a product part list, available budget, desired production rate, delivery time, system up-time, and space constraints. Figure 1 is an example of customer requirements from the crayon manufacturing case study. For a system integrator, the main focus is to understand the requirements from the customers in as much detail as possible. Common requirements include cost, production rate, system up time, and delivery time. The proposed conceptual design in the proposal should transform these needs into concrete design features that achieve the requirements.

Quality Function Deployment (QFD) is a method originally developed by the designers of Japanese automobiles to prioritize needs into concrete actions and metrics. Figure 2 shows the QFD "House of Quality." The customer requirements are written on the left square with the label of 'WHAT." A rating of the customer requirements is also listed in the same square. Based on these, system integrators can create columns that list "how" the customer requirements might be satisfied and measurements needed to access the technical requirements. The square on the right is used to document customer perceptions of competing products. Figure 3 is an illustration of QFD applied for a product (a kitchen broom). The needs are translated into technical requirements with process parameter target values to be controlled.

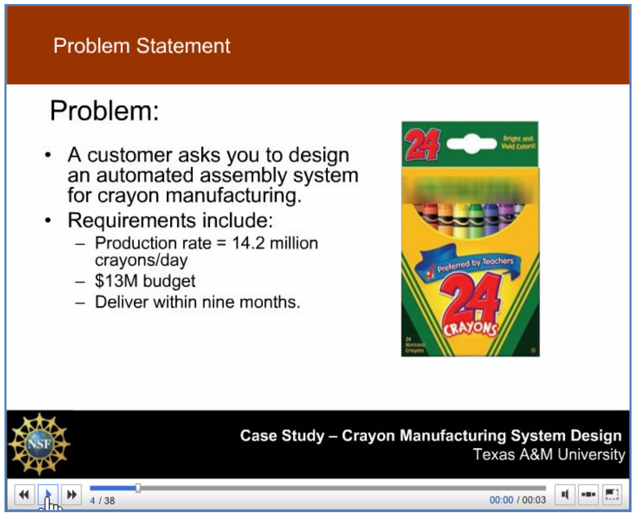


Figure 1. System requirements

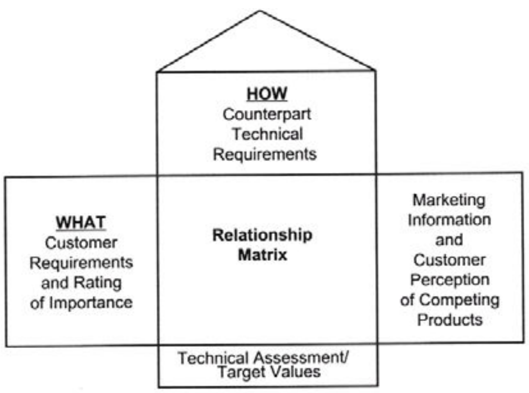


Figure 2. Quality Function Deployment

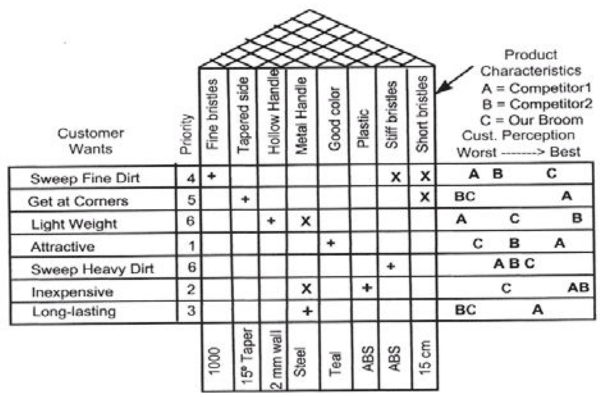


Figure 3. Quality Function Deployment Example

2. Collect data

An application engineer at a system integration company will want to collect as much detail as possible about the part list, process requirements, and how parts will be presented to the assembly line. For example, will the parts be delivered in a tray or a box? Will they come from another sub assembly line or be shipped from a vendor? Is a machine needed to check the parts before assembly? How big is a lot? How often do you need to refill the part feeder? Are there any pre-existing machines that need to be incorporated into the line?

3. Determine the Assembly Sequence and Cycle time

Given the required production rate, system up-time and part list, an optimum assembly/manufacturing sequence can be designed. Figure 4 shows the crayon manufacturing process. A precedence diagram (shown in Figure 5) will be constructed based on operations precedence relationships; then a line balancing method, such as Largest-candidate rule, will be employed to combine work elements into a workstation, and the original cycle time will be calculated. After that, balance delay can be calculated to measure line inefficiency and the original cycle time will be compared with the desired cycle time derived from the predicted production rate. Parallel workstations and/or multiple identical production lines will be arranged to reduce default cycle time and/or reach the desired production rate. Figure 5 shows parallel workstation and parallel lines arrangements and Figure 6 shows the calculation of cycle time. The desired workstation arrangement is for each station to have the same operation time and the line inefficiency to be zero.

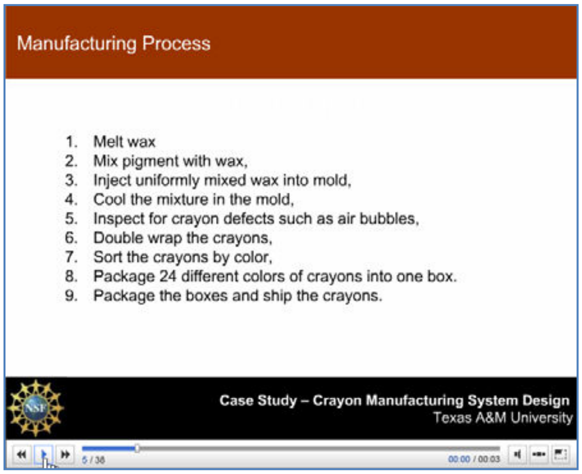


Figure 4. Major steps in crayon manufacturing process

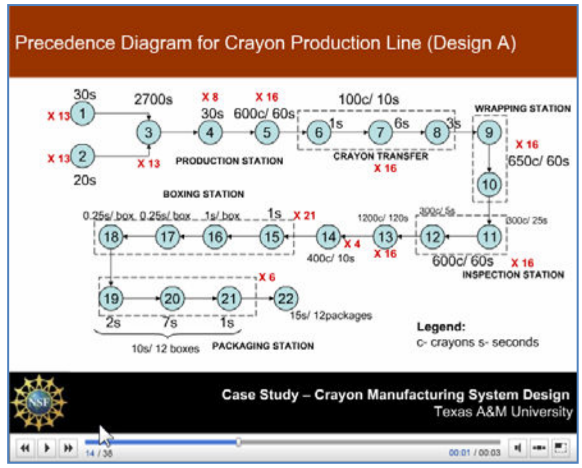
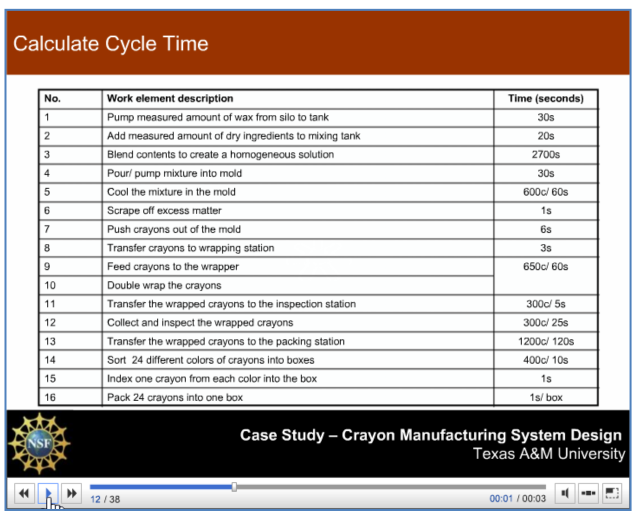


Figure 5. Precedence diagram for design alternative A



Calculate Cycle Time

No.	Work element description	Time (seconds)
1	Pump measured amount of wax from silo to tank	30s
2	Add measured amount of dry ingredients to mixing tank	20s
3	Blend contents to create a homogeneous solution	2700s
4	Pour/ pump mixture into mold	30s
5	Cool the mixture in the mold	600c/ 60s
6	Scrape off excess matter	1s
7	Push crayons out of the mold	6s
8	Transfer crayons to wrapping station	3s
9	Feed crayons to the wrapper	650c/ 60s
10	Double wrap the crayons	
11	Transfer the wrapped crayons to the inspection station	300c/ 5s
12	Collect and inspect the wrapped crayons	300c/ 25s
13	Transfer the wrapped crayons to the packing station	1200c/ 120s
14	Sort 24 different colors of crayons into boxes	400c/ 10s
15	Index one crayon from each color into the box	1s
16	Pack 24 crayons into one box	1s/ box

Figure 6. Cycle time calculation

4. Select assembly line components

This task involves making decisions about (1) the number of machines for each station; (2) the types of machines and machine capacity for each station; (3) types of material handling and transfer equipment needed, (4) types of part feeders and machine tools required, (5) number of operators, and (6) number of work shifts needed to manage the assembly lines. All these factors will affect the overall cost of the proposed design. Therefore, a few alternatives may be proposed. For example, in the crayon manufacturing case study, to achieve the desired production rate of 14.2 million units per day, the design incorporates parallel stations/machines.

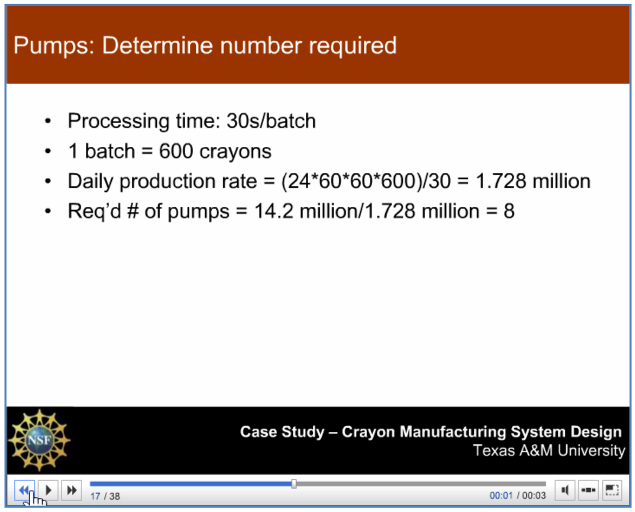


Figure 7. Calculating amount of equipment needed.

5. Determine layout of assembly line

There are three common line layouts: inline, U-shape and parallel cell configurations. The goal is to reduce material transfer time (since transfer is not a value-added process) and to increase the feedback. The crayon manufacturing system incorporates 13 to 16 parallel lines (illustrated in Figure 8). The inline layout allows raw materials to be placed at one end and finished product at the other.

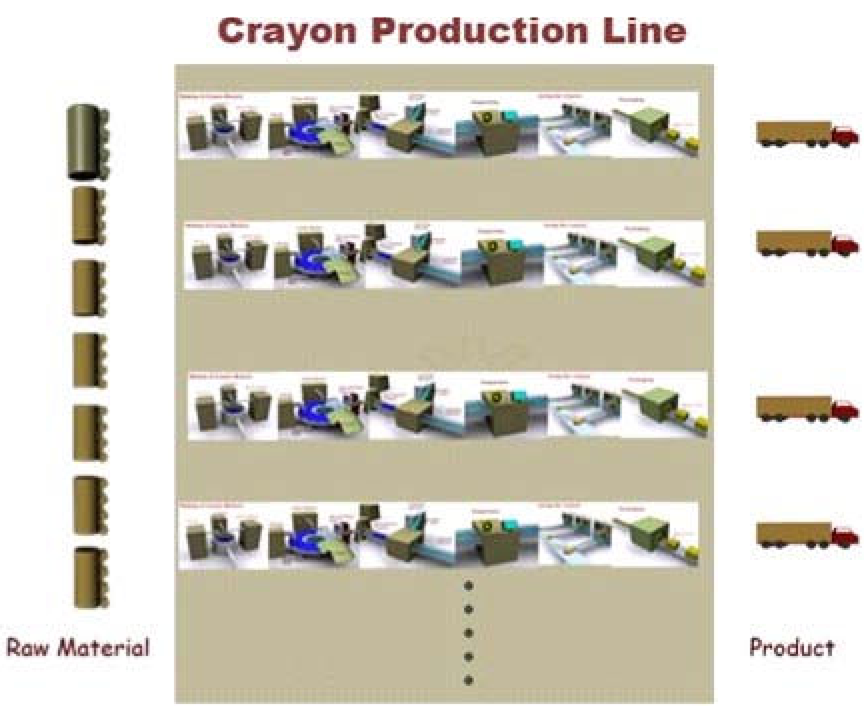
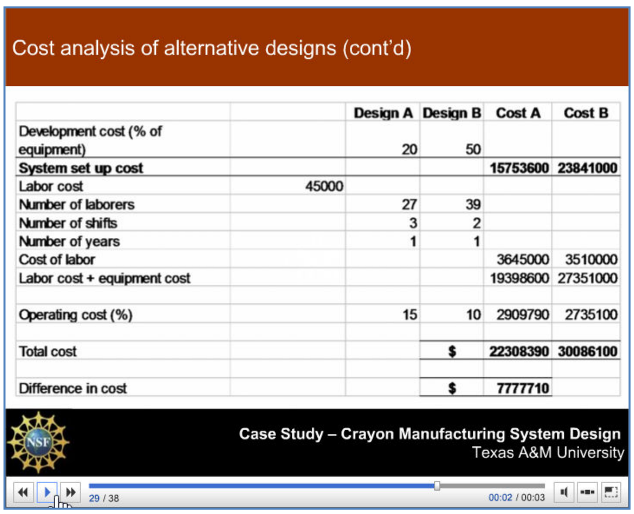


Figure 8. Proposed inline system layout.

6. Perform cost estimation and analysis

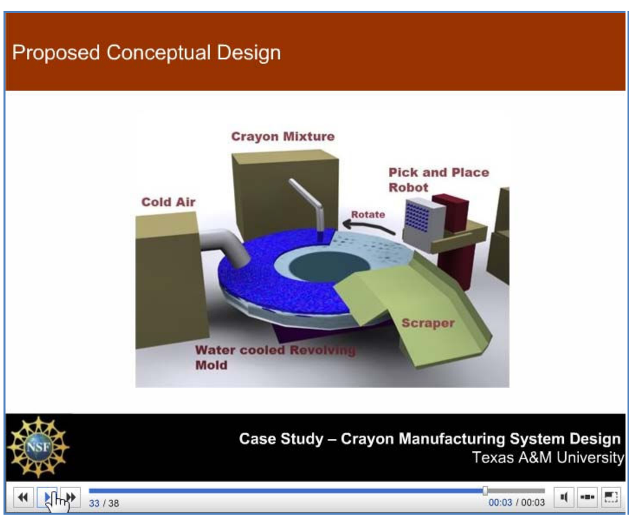
Cost categories include labor cost, machine/equipment cost, materials cost, system development cost, and overhead. Several alternatives may be proposed. Customers may choose an alternative based on its rate of return, request a hybrid of two or more of the proposed alternatives, or not accept any proposed design. In the crayon manufacturing case study, two alternatives are proposed (Figure 9). One alternative is to have fewer parallel workstations and parallel production lines but work three shifts (Design A) versus more parallel workstations and production lines but work two shifts (Design B).

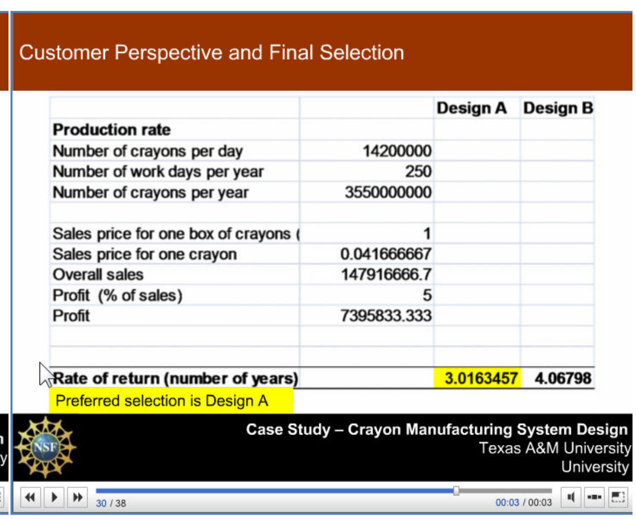
Figure 10 shows the molding process from the proposed conceptual design and Figure 11 shows that conceptual design A was favorable due to its higher rate of return given the same unit profit.



		Design A	Design B	Cost A	Cost B
Development cost (% of equipment)		20	50		
System set up cost				15753600	23841000
Labor cost	45000				
Number of laborers		27	39		
Number of shifts		3	2		
Number of years		1	1		
Cost of labor				3645000	3510000
Labor cost + equipment cost				19398600	27351000
Operating cost (%)		15	10	2909790	2735100
Total cost			$	22308390	30086100
Difference in cost			$	7777710	

Figure 9. Cost comparison of designs A and B





		Design A	Design B
Production rate			
Number of crayons per day	14200000		
Number of work days per year	250		
Number of crayons per year	3550000000		
Sales price for one box of crayons (	1		
Sales price for one crayon	0.041666667		
Overall sales	147916666.7		
Profit (% of sales)	5		
Profit	7395833.333		
Rate of return (number of years)		3.0163457	4.06798

Figure 10. Conceptual design - crayon molding

Figure11. Customer selection.

Conclusion and Future Directions

The crayon manufacturing case study is an example of a system for a discrete manufacturing process. Future case studies will also focus on systems for continuous processes (such as oil refining) and for hybrid processes (such as beverage manufacturing, and also on machine and system design. Case studies may also incorporate other steps in the design process, such as design analysis (including cost analysis) and ranking; prototyping; and field test/engineering changes.

Acknowledgements

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