”Doing Engineering in the School of Letters & Science: Adding a Manufacturing Line Design Project to a Writing Program Class for Engineers”

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Introduction

For many years, professional and armchair philosophers alike have debated the paradox, which came first—the chicken or the egg? A similar dilemma has challenged instructors regarding the design and delivery of discipline-specific technical report assignments for engineering students. Which ought to come first—the topic or the document? Should report writing be integrated into engineering courses as a complement to course-determined labs, design projects, and exercises? Or should report writing be taught in courses delivered by writing programs, in which instruction usually begins with theory and form associated with report documents themselves? In those courses, unless the writing class is partnered as an adjunct to an engineering course, students must seek relevant content on their own, via library research, individual linkages to engineering classes, research projects, or industrial internship experiences. Many universities believe the best compromise is to do both in parallel.

So which is the best practice—let the topic lead the document; let the document lead the topic, or a combination of the two? A review of the current literature (see next section) indicates that the jury is still out on which approach is more effective. All of the pedagogical scenarios have produced successful outcomes as well as educational challenges. This paper notes admirable headway in all three camps, and explores in detail the first offering of an engineering report writing assignment that brings an engineering design project into an upper-division writing class hosted by a university writing program, separate from Engineering, “on the other side of campus” in the College of Letters & Science.

This case study documents the roll-out, emergent issues, and result of the first offering of this report writing assignment at University of California, Davis, to a class of 21 junior- and senior-level undergraduate engineering students, working to fulfill their upper-division GE writing requirement during Winter Quarter 2012. In addition to teaching the students a recommended design and rhetorical structure for the report document, the assignment also supplied students with the prerequisite theory and a technical situation that would enable the students to engage in a basic manufacturing line design project, with the report being the project’s documentation vehicle. The instructor, a retired mechanical engineer, modeled the project after his industrial work experiences at Hewlett-Packard Inkjet.
The assignment hypothetically places the student-engineers at a robotics company, preparing a trade show exhibit to showcase the technical and economic advantages of automated assembly of small-scale, high-volume products. The demo line is to target production of 1M miniature Lego cars. This product is similar in size and material type to an inkjet pen’s economical yet brittle plastic printhead and reservoir housing, but more familiar to the students designing the product.

To keep the assignment’s engineering design component macroscopic, so as not to eclipse the writing component (nor interfere with and/or contradict the students’ more advanced lessons in design in their engineering design classes proper), the instructor supplied students with a menu of suitable and viable, cost-labeled and Programmable Logic Controller (PLC)-equipped conveyors, shuttle pallets, pick-and-place arms, flip-over stations, vibratory bowl feeders, and machine vision units to use in their designs. Thus, the writing assignment’s design element focused on system-level workflow, rather than details. The final project deliverable was an 8- to 12-page report recommending an optimal conveyer type and tooling to meet target yield and budget specifications.

In test-teaching the assignment, the instructor’s objectives were as follows:

1. Observe how students respond to the assignment and determine to what extent they perceive educational benefit(s) toward developing their engineering communication skills.

2. Reveal emergent issues and how to fix them.

3. Observe the students’ reaction to the supplied topic for their assigned report documents and determine to what extent the students view a turn-key, macroscopic manufacturing line design project as a relevant and sufficiently complex technical challenge, rather than something that’s too easy or artificial.

4. Use the assignment to gauge the feasibility of combining the study of a technical topic and document form/theory in a writing program class. Although most writing program instructors do not have engineering degrees, this paper’s author assumed that if the trial proved successful, then similar turn-key, macroscopic project scenarios could be supplied by Engineering (or an industrial partner) for use in other writing program classes for engineers that teach report writing. The author also assumed that writing instructors with primary expertise in rhetoric/composition would need to receive instructional guidance from the content sources; and would be willing to allow the assignment’s engineering design element be student-centered and horizontally managed. The writing element could remain instructor-led.
5. Design and execute a new writing assignment that supports ABET Student Outcome “g”—an ability to communicate effectively.

The assignment’s chief Student Learning Objective (phrased Mager-style) was as follows: Given prerequisite instruction in manufacturing line design basics for small plastic products and in the theory and structure associated with technical report documents centered around the Mode of Evaluation; a turn-key, macroscopic design project; and detailed project and document specifications; the student engineer will successfully complete the project and present an optimal design configuration in an engineering report—such that the report explicitly adheres to all project and document specifications and exemplifies writing that is clear, concise, correct, complete, and convincing.

Historical Context and the Literature

This author of this paper—who has taught for the writing program at University of California, Davis, since 2002—first became acquainted with engineering writing instruction in the academy at another campus, when he was hired in 1989 by the College of Engineering at University of California, Irvine, to teach a senior-level engineering professionalism class, Engineering 190W. The class satisfied 4 units of upper-division G.E. writing, and was developed by a Writing-Across-the-Curriculum (WAC) pioneer and chemical engineering professor, Dr. Frederick T. Sawyer. Sawyer authored the equally ground-breaking book-on-tape series, Oral Communication and People Problems, published by American Chemical Society (ACS) Publications in 1977. Engineering 190W still thrives at UC Irvine today and serves as an excellent example of melding instructional design with ABET communication criteria.1

Also during the 1980s, the first iteration of a 4-unit engineering writing course was co-developed by the College of Engineering and the campus writing program at University of California, Davis. An updated version of that same course is still offered at the Davis campus, and this paper’s subject assignment is situated within it.

The author must acknowledge, however, that probably the most high-profile, and distinguished, engineering writing program circa the 1980s was delivered by the College of Engineering at University of Washington. Washington’s program offered multiple courses, lower-division and upper-division, and championed the topic-leads-document-follows model. Since then, engineering programs have been working to define a best method for teaching and characterizing engineering writing, a sub-genre that must be both exact and utilitarian to serve its purpose.2 For the record, according to Teresa C. Kynell, whose scholarly focus is technical writing as a genre,
Engineering writing has been recognized as something distinctive for over a century. In fact, as the broader genre of technical writing has evolved over time, Kynell asserts its ties with engineering education, and so-called “Engineering English,” have grown all along the way.3

In recent decades, more good work has gone into further advancement of writing instruction pedagogy for engineers—and a variety of methods and sources of delivery have been explored. A recent investigation by House et al. queried technical communication educators at a broad range of colleges and universities, and determined that the delivery of technical communication courses for engineers, as of 2007, was done more often outside of Engineering than in.4 Nevertheless, a growing number of engineering schools offer “in-house” engineering writing courses—as well as courses focusing on oral communication skills and general professional soft skills. For example, such a course, taught within the Chemical and Bio-molecular Engineering Department at North Carolina State University (NCSU), was celebrated in a recent article in Prism magazine.5

Fully acknowledging the long list of noteworthy programs in engineering writing now in-place is a daunting task. Benchmarks include the programs offered by Massachusetts Institute of Technology, Texas Tech University, Virginia Tech University, Rensselaer Polytechnic Institute, already-mentioned NCSU, along with Georgia Institute of Technology, New Mexico Tech, Montana Tech of the University of Montana, and University of Southern California. This list is brief, and there are many other examples.

Continuous improvement in the teaching of engineering writing is ongoing in courses which use both the topic-leads-document-follows, and document-leads-topic-follows approaches. Moreover, during the past 5 to 10 years, engineering writing classes have brought in peer coaches, creative writing exercises, and document portfolios for engineering students. Heylen and Sloten along with Jacquez et al. are among the many educators and scholars focusing on innovations in teaching writing specifically within engineering design courses, freshman-through senior-level.6 7 Instead of offering one custom writing course for engineers, a growing number of universities are boasting series of two or three. University of California at Santa Barbara offers a particularly impressive 3-course series that incorporates a unique mixture of studying engineering literature, doing in-class product autopsies and writing about electromechanical devices purchased at thrift stores, and studying standardized report and proposal forms.8

Moreover, educators have been developing rubrics to make the evaluation and grading of engineering reports more efficient and effective.9 10 Investigators are looking at new techniques...
for engineering writers to enhance the persuasiveness of proposals and cover letters.\textsuperscript{11} Some educators, like Dr. Chad A. B. Wilson at University of Houston, have figured out how to use popular, mainstream novels to teach engineering writing.\textsuperscript{12} These are exciting times. Someday soon, “engineering writing” might well become a brand name genre akin to “science writing”—accepted and known widely by academics and laypersons alike.

Case Study

This paper develops its case study, first, by presenting both the specifications for the subject writing assignment’s topic and document. Second, the case study describes the subject writing assignment’s rollout and execution over a 5-week period. Next, the study records emergent problems that arose along the way and how they were addressed in-progress. Finally, the study presents the results.

\textit{Topic}

A hypothetical company given a business scenario generates a project, which yields a report topic for a university writing program class in engineering writing.

\textit{hypothetical company:} To establish practical context, the assignment immersed students in a simulated project conducted at a hypothetical company, “Maverick Robotics Corporation,” a successful high-tech operation in business since the early 1960s. This mock company is modeled after Midwest Automation, a real robotics supply company and frequent sub-contractor for Hewlett-Packard Inkjet manufacturing lines. Maverick Robotics Corporation (MRC) sells a diverse line of commercial automation equipment for products ranging from automobiles to packaged foods to computer printers. One of MRC’s claims to fame is its turnkey solution, high-speed, synchronous manufacturing modules (THSMMs).

The THSMM product line allows manufacturers seeking to automate high-volume manual assembly operations the option of a line built from interchangeable modules and mix-and-match attachments and stations, instead of having to design and build a manufacturing line from scratch. MRC’s THSMM suite features an assortment of base unit conveyer systems, already wired with PLC units, 220 V power supplies, tool mounts, and plug-in points for robotic stations. The modules also have options for pre-plumbed hydraulic, pneumatic, and vacuum supply line systems.
In addition, there are a number of bolt-on robotic tooling options for modules including injection, pick-and-place, and flip-over stations; custom-to-order shuttle pallets, punches, and drills; machine vision monitors, bins, and bowl feeders; and more. To order a custom THSMM solution, customers need only submit a set of design drawings for the product to be assembled; numbers for volume, quota, and maximum tolerated scrap rates; and a specific work flow scheme (detailed flowchart) that presents a desired conveyor module scheme along with types and sequences of assembly operations and process monitors to accessorize the module.

**hypothetical scenario:** The students are to assume MRC is scheduled to celebrate its 50th anniversary of continuous operation and excellent profit margins, by showcasing this milestone at an upcoming tradeshow in Las Vegas, an event that MRC regularly attends and at which MRC secures new accounts and customers. MRC also regularly one-ups its chief competitor—Midwest Automation, Inc.—at the Las Vegas Automation Tradeshow. MRC wants to be sure to do this again.

**the project:** The students were instructed to assume they are currently employed at MRC as level-1 engineers, and that their boss at MRC has assigned them a project. The project calls upon each student to evaluate options and recommend the best work flow scheme for a small-scale THSMM demo line to be featured at the upcoming Las Vegas Automation Tradeshow. The demo line will be located nearby the MRC booth on a 10-by-10 ft² section of industrial floor space. The project’s chief deliverable is a written report that presents a winning manufacturing line design tailored to meet the project’s objective. After conceptual buy-off, the report writer is to assume that a team of senior engineers at MRC will take it from there, and go on to ensure the line receives additional refinement and gets built. Given that the chief business aim at the tradeshow exhibit is positive PR, the line intends to demonstrate the versatility and quality of MRC’s modular robotics by showcasing a working miniature of a fully automated production system.

The demo’s manufacturing purpose is to replace a factory operator who works 8-hr shifts, 5 days per week, and who is charged with manually assembling one million (1M) LEGO miniature sports cars. The tradeshow exhibit will feature a cost and benefits analysis poster next to the exhibit that compares expense and output of one dedicated factory worker (manual) versus that of one dedicated assembly line (robotic).

Why LEGO? The marketing department at MRC has decided to go with a LEGO miniature sports car as the demo product, because (a) the toy car carries with it a tradeshow “fun factor” and (b) a “branding” angle that makes Maverick Robotics a popular company is its reputation for
being known by employees and customers alike as the place that makes “Legos for big manufacturing engineering boys and girls.”

**The design specifications:**

- product is a 2012, model #9480, LEGO car. (See Figure 1.)
- product retail is $9.00/unit, cost to manufacture car parts is $0.75/unit.
- target quantity is one million (1M), required production rate is as many units per day as possible, and acceptable scrap rate is 1%.
- salary rate (X) of the benchmark factory worker is $18.50/hr, with a payroll, taxes, and benefits factor (PTB) of 1.4X.
- product assembly comprises 16 pieces as shown in Figure 2 (below).
- pre-approved MRC parts and costs are as follows:
  - linear conveyor module (specify 4-, 6-, or 8-ft length), with PLC unit, two (2) moveable mount (bolt-on) machine vision camera/processors, pneumatic and vacuum supply plumbing, custom shuttle pallet fitted to under-side of LEGO car chassis, and select drive (specify synchronous go-stop-go, steady advance, or steady advance notched for pallet clutch option), $30K (for all options).
  - continuous conveyor module (oval profile, 2:1 L:W ratio, specify 4-, 6-, or 8-ft track length), with PLC unit, pneumatic and vacuum supply plumbing, custom shuttle pallet fitted to under-side of LEGO car chassis, and select drive (specify synchronous go-stop-go, steady advance, or steady advance notched for pallet clutch option), $50K (for all options).
  - pick-and-place station, small, servo-powered spindle base with 360 degree rotation, servo-powered X-Y plane arm with 1-foot reach and light-load gripper (specify pneumatic vise-action or 2-hole, female-to-male Lego-match vacuum plate), $4.75K (for all options).
  - pick-and-place station, small, servo-powered X-Y-Z plane arm and sliders with 1-foot reach and light-load gripper (specify pneumatic vise-action or 2-hole, female-to-male Lego-match vacuum plate), $3.5K (for all options).
  - pick-and-place station, small, servo-powered full 6-degrees-of-freedom arm with 1.5-foot reach and light-load gripper (specify pneumatic vise-action or 2-hole, female-to-male Lego-match vacuum plate), $7.25K (for all options).
- part supply station, vibrational bowl feeder, can be customized to deliver and present any LEGO part or sub-assembly, one pick-up orientation option, $1K ($1.5 K for two pick-up orientations, e.g., standard and flipped/rotated).

- moveable mount (bolt-on) machine vision camera and processors, $0.25K each.

- pick and place stations can only approach product in-process from one direction, side or top; thus, some operations will require more than one pick and place.

- note: MRC parts not listed above can be considered and used, provided they receive special approval by manager (AKA, instructor). For special approved parts, if approved, the manager will supply pricing.

- project engineer must consider, analyze, and present performance data and pricing for the manual labor option (baseline) and two or more automated work flow options/variations, and from the latter choices, he or she must recommend a best option to MRC management to implement at the upcoming Las Vegas Automation Tradeshow.

- presentation of results must include work flow schemes (flowcharts) and performance and cost analysis tables, and be submitted within a formal, comprehensive, written report.

- as with most real-world projects, to achieve a successful outcome, it is likely that the problem-solving process will require the engineer to consider implicit and emergent criteria. These factors might include indexes, assumptions, constraints, costs, and so on, above and beyond the initial list of “givens” and “specifications.” To negotiate the “non-givens,” the level-1 engineer is advised to do his or her best, employ system-level and out-of-box thinking, be creative (but not rash), and take comfort in the fact that it is the norm for real-world projects to have more than right answer.

\[\text{Figure 1: 2012, model #9480, LEGO car}\]
the rhetorical structure: Since engineers are often assigned to evaluate several alternatives to solve an engineering problem and then pick a winner from among the choices, an essential rhetorical structure to master is the Mode of Evaluation. To orchestrate a successful evaluation, the engineering writer must center it around a data-driven argument. This requires proper setup, valid data, methodical analysis, and conclusions/recommendations based upon objective/quantitative rather than subjection/qualitative reasoning. For this project, the assignment’s topic partners well with the assigned document, because the Mode of Evaluation governs the project’s decision-making.

To ensure knowledge of the subject assignment’s report structure, in addition to detailed guidelines on how to write and what to put in each section, the instructor also provided a flowchart to help the left-brain student “see” the document’s work flow. Figure 3 illustrates this flowchart.
The level-1 engineer must document his or her project in a formal technical report. Target length of this report is 10 +/- 2 pages. The report must be divided into the following sections: Cover page, I. Summary, II. Introduction, III. Feasible Alternatives, IV. Projected Performance and Cost Analysis, V. Results, VI. Conclusions and Recommendations, and VII. Appendix.

- The resource file, 102e_TR_outline_rev_e.doc, posted on the class web page, will provide expanded guidelines on content requirements for each section.

- The report’s text should be double-spaced in 12-point, NTR font. Section headings should be typed in boldface, and subsection headings (where applicable) in italic.
The Results section must show work flow diagrams (flow charts) for the two (or more) automated alternative solutions. The Results should also contain a top-down-view sketch (to scale, but block diagrams of equipment section okay) showing how the real equipment will fit into the 10 x 10 sq ft of available floor space in Las Vegas. The Results should also tabulate numbers for projected performance and cost of each of the several alternate automated work flows. For easy compare and contrast, the table(s) should include numbers for the baseline manual labor option and for targeted project criteria.

- the report must be built out of sentences that are concise, clear, and correct.

**Rollout and Execution**

A class of 21 junior- and senior-level engineering students undertook the subject writing assignment under the constraint of a 5-week timeline. The duration of the class was 10 weeks. The project started week 3 and concluded week 7. Optional further rewriting was allowed during the final 3 weeks of the class. The weighting of the assignment relative to overall class grade was 25%. During the assignment’s 5-week timeline, there were concurrent assignments.

To advance the assignment execution, the instructor coached the students through a four-phase process that integrated the four key steps of writing—prewrite, freewrite, rewrite, and edit—with four key steps of design—fact find, brainstorm, create/iterate, and perfect. Below is a summary of the activities advanced in each of the four phases. Figure 4 maps the phases against a timeline.

**phase one = (prewrite) + (fact find):** The instructor launched the assignment with a quick-start lecture on high-speed synchronous automated assembly systems for high-volume products made out of small, relatively fragile, injection-molded plastic pieces. He handed out the instructions for the assignment. To integrate discipline-specific writing approaches with the assigned report topic, he presented a flowcharted algorithm for structuring an evaluative report using data-driven logic to compare and contrast engineering options, and then mapped this structure into the textual sections of a technical report. The instructor showed the class an example of the Lego car product to be assembled. Phase one consumed one class period.

**phase two = (freewrite) + (brainstorm):** The instructor gave a second quick-start lecture on high-volume manufacturing, this time focusing on useful tooling for presenting and manipulating small, plastic components—vibration bowl feeders, pick ‘n’ place stations, flip-over stations, and sensors. He used YouTube videos to illustrate examples of each tooling. He also showed a 20-minute video that took audience members, station-by-station, through the work flow for an inkjet...
pen manufacturing line. He divided the class into small teams and gave each team a plastic tub with a disassembled Lego car. The instructor asked each team to manually assemble their car and then brainstorm and sketch a work flow diagram for automated assembly of the car. The instructor concluded the class with Q & A and a 10-minute freewrite. Phase two consumed one class period. The students were directed to complete a rough draft of their reports in-progress by the start of week three.

*phase three = (rewrite) + (creative/iterate):* This phase involved one class period and two special 2-hr office-hour sessions outside of class. The students exchanged report drafts and critiqued each other’s work. Several emergent issues presented (see next section) and were resolved in-class during lively Q & A sessions with the instructor and in general class-level dialogue.

*phase four = (edit) + (perfect):* During the final phase, one half-class session addressed the project. There were more special office-hour sessions outside of class. The one-on-one and small group office hour discussions were keen and enthusiastic. Several students conducted outside research to advance their projects, especially regarding their cost analysis sections. These students were eager to share their findings during in-class Q & A. All but 1 out of 21 students total turned in their reports in on-time.

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*Figure 4: Project Gantt Chart*

**Emergent Issues and Fixes**

The following problem-solution pairs represent the productive, problem-solving dialogue that went on between instructor and students once the students’ design projects and complementary report projects were in-progress:

*Q: Should the two (or more) tooled-up assembly line alternatives be radically different from one another?*
A: Presenting two (or more) variations of one solid idea is acceptable. For example, your report might say, “the best concept of a work flow schema for my line that resulted from brainstorming sessions was an X-type conveyor with Y stations, configured in the following order ... and, thus, I explored two variations governed by the line's bottleneck station, Z, to optimize process flow...

Q: When doing the economic analysis of options, what about power usage, line maintenance costs, cost of downtime incidents, etc.? Should we consider operation costs such as these?

A: Yes. It is highly likely that the engineering readership of your report—and, later on, the engineering audience at the tradeshow—will wonder about such things. These are implicit solution criteria that need to be addressed. Don’t go overboard, however. It is satisfactory to clearly, yet succinctly, acknowledge additional factors in the text of your report (preemptive strike tactic) and then offer reasonable estimates for how they might impact total cost. Consider the process of benchmarking to arrive at credible numbers for such costs.

Q: What about time and cost targets? The project specifications do not cite any specific targets.

A: The answer is: think bottom-line and go for deltas. The audience you’re trying to impress, mainly, would like to see a significant difference between what it might cost, and how long it might take, to produce 1M cars manually vs. robotically.

Q: What’s the best way to calculate production rates?

A: The answer is that for manual production, first off, the engineer needs to make a reasonable assumption for production rate per car, and state that assumption in his or her report. To arrive at this figure, the student should try assembling the Lego car her/himself, on a timer. Then extrapolate. Imagine assembling cars, one after another, on an 8-hr shift. Figuring an average 5-minute production rate for manual assembly is reasonable guess. But could someone sustain this production rate for an 8-hr shift? Factor this in. Also figure in work breaks. For the automated line, a safe estimate of individual process cycle time would be 2 seconds per station. Some stations might operate faster, but bottleneck speed would be around 2 seconds. This means maximum achievable production rate for the line would be 2 seconds per car.

Q: After perfecting a best work flow flowchart, when next preparing a line’s top-down layout, what sort of buffer space needs to be factored in around the perimeter of the oval carousel or sides and ends of the linear conveyor?
A: This buffer accounts for protrusions of bolt-on tooling and feeders. A two-feet extension all the way around the line itself is suggested. An additional free space buffer of 1 foot, at 3 feet total, for safety and tidy aesthetics would be even better.

Results

The Instructor’s Evaluation

At the end of the 5-week project timeline, on the due date, 20 out of 21 students submitted their reports. The missing report was completed and submitted several days late. Judged against the assignment’s Student Learning Outcome (SLO) criteria (repeated below), from the instructor’s point of view, the quality of the reports was uniformly good to excellent. The reports were consistently “written to spec” and developed in a clear, concise, correct, complete, and convincing fashion. The students’ manufacturing line designs were generally novel and sound. Appendix A presents an example of an “excellent overall” student report.

The SLO criteria: (the student engineer will successfully complete the project and present an optimal design configuration in an engineering report)—such that the report explicitly adheres to all project and document specifications and exemplifies writing that is clear, concise, correct, complete, and convincing.

Although the instructor strived to be unbiased, the instructor’s assessment must be viewed as notable, yet subjective.

Third-party Evaluation of Student Feedback

To collect objective feedback, toward the end of the 10-week academic quarter, after the graded reports had been returned to students, the instructor gave a follow-up activity calling upon the students to reverse evaluate the class’ new engineering report assignment and method. The students were assigned to write a one- to two-page reflective statement responding to the prompt below. The students were directed to target as primary audience the Dean of the College of Engineering, with peers and the instructor being a “transparent” secondary audience.

Prompt: "How and why (or why not) did your experience working on the Lego car assembly line Report Project provide you with educational benefit(s) toward developing your engineering communication skills?"
To remove instructor bias from the review of student feedback, the instructor solicited assistance from a third party analyst in assessing/analyzing the student responses. Although all 21 students turned in reflective statements, only 19 submitted softcopies. Those 19 were transmitted electronically to the analyst for assessment. The analyst was directed to give equal attention to both positive and negative feedback. The analyst examined the 19 reflective statements to discern and record what the analyst viewed to be common themes and representative quotes.

The text of analyst’s email report back to the instructor on themes (positive and negative) appears below. Positive themes were prevalent. Negative themes were minimal.

"Despite being given a subjective prompt rather than a scaled survey or objective instrument, many of the students’ reflective statements repeated similar benefits. These include variations on the following characterizing statements ...”

**positive themes**

- The class left the students better prepared for the real world / a job in engineering / professional life.
- The students learned a substantive amount about writing concise, effective reports for the business-world.
- The students gained experience in analyzing data to determine the best solution to a real-world problem.
- The students learned how to successfully present data through graphs and figures.
- The students learned how to convert engineering-type ideas into a readable report.
- The students improved their skills in designing / structuring / formatting reports.
- The students were pushed to engage in open-ended problem solving that required making assumptions / doing additional research / sharing findings with peers because not all necessary data were provided.
- The students viewed the teamwork component to be a positive experience or reported on what they gained from it: group work clarified the next steps / group work enhanced creativity / group work helped the student improve spoken / interpersonal communication.
- The students viewed the project to be fun / original/ not textbook.

**negative themes**
• One outlier student thought the assignment was too easy (!).

• Another outlier student communicated he was pleased with his final design and report outcome, but disliked being “spoon-fed” during the project start-up.

**mixed theme**

• Several students stated they were initially confused because the instructor did not provide enough data / information in the beginning. Of these, most ended up feeling they benefited from and were challenged by the need to do research (which appears to have been one of the purposes of the assignment). One student decided that data not provided was not relevant and did not need to be accounted for.

In an effort to showcase the spectrum of feedback, both true to overall consensus and the “voice” of the students, the analyst also extracted quotes from the 19 reflective statements. Examples are cited below. The writing in the quotes is original to the students’ except for bracketed edits. All references to specific university, instructor, and class were either deleted or changed to generics.

**student quotes**

“... by writing this report, I learned that the organization of a technical report, as well as the stylistic choices of how I present data, might be just as important, if not more important, than the data in the report itself.”

“The Lego car assembly line report project improved my engineering communication skills because the project allowed me to practice with an effective technical report template.”

“The LEGO car assembly line project enhanced the analytical tools I already have (problem-solving, big-picture analyzing, number crunching), and made me apply those tools in a way that they would be used in an industry setting. The project also gave me a sense of perspective on what types of analyses I need to perform; most, if not all, engineering projects require at least a cost- and time-efficiency analysis.”

“I learned the most writing the conclusions and recommendations section, because it required me to convert engineering analysis results (such as payback period and per unit cost) into writing.”
“Another good experience from this project was being forced to make certain assumptions and do research on appropriate specifications in order to complete the analysis of the report. This definitely took me out of my comfort zone since these were not necessarily consistent with the rest of the class and could lead to different numbers for the conclusion.”

“[We studied] the importance of the logical flow in a technical report written for industry. Specifically, the report taught us how to develop a document that takes the reader through each stage of the project in a systematic fashion from the initial concept, to the design phases, to the results, and ending with the final recommendations.”

“The LEGO car report gave me a useful example of how to balance number and word-based results.”

“During the time I was involved in the LEGO car report project, I felt like I was an actual engineer and I was writing a report for my boss.”

“Getting in groups and talking about different ways to assemble the line of robots moved the project from an abstract idea to a concrete project.”

“An engineer has to be able to analyze many different types of problems and find feasible solutions. My civil engineering core coursework at [my university] has taught me these skills. This project helped me take these skills and apply them to writing a report.”

“I needed to generate figures, diagrams and data tables that were clear and quantitative. I learned how to make a work flow diagram and realized while writing my report that [the diagram] served as a good way to clearly present an overall view of the proposed solution and that it did not need to include too many technical details.”

“Time management proved to be the most difficult aspect of this assignment. I completed the majority of the report (Results, Conclusions and Recommendations, and Summary) during the night before the deadline. While I managed to finish and submit the report on time, I intend to improve my time management skills to avoid future instances of procrastination.”

**Discussion**
A retrospective discussion of the case study put forth in this paper invites a return to the paper’s beginning: first, to re-visit the instructor’s objectives in test teaching the subject writing assignment, and, second, the Student Learning Outcome (SLO).

A scroll through the cluster of five instructor objectives’ invites the following post-delivery appraisals:

1. The instructor observed, both directly in the classroom and indirectly in the student feedback data that a majority of the students responded positively to the assignment and perceived educational benefit(s) toward developing their engineering communication skills.

2. Several emergent issues revealed themselves once the project was underway. They were predominantly questions about cost analysis, operation, and maintenance that needed to be answered for students to proceed further. These questions were resolved by additional input from the instructor and by additional outside research by the students themselves.

3. The students’ reaction to the supplied topic for their report documents was predominantly favorable. They viewed the turn key, macroscopic manufacturing line design project to be relevant, realistic, and sufficiently complex.

4. Whether this type of assignment has feasibility and good fit for usage in other writing program classes remains to be decided. The author recommends other writing program instructors give it a try—with the provision that instructors with primary expertise in rhetoric/composition have access to instructional guidance from their engineering content sources; and let the assignment’s engineering design element be student-centered and horizontally managed.

5. Whether the new writing assignment explicitly connects well with ABET outcome “g” remains to be decided. This needs to be assessed with further rigor when the subject writing assignment is used again.

The instructor believes that the assignment achieved its chief SLO as discussed in the Instructor’s Evaluation sub-section of Results. This preliminary response, though positive, is acknowledged as subjective, and merits further investigation when the assignment is offered again.

A section of the engineering writing class that includes the subject assignment is scheduled to be delivered Spring Quarter 2013. The author will teach this class and assign the Lego car assembly line report project a second time. A goal for his second delivery is a more formal
assessment of the assignment’s outcome, using a scaled assessment instrument collecting quantitative data. The next version of assessment will also mine for relevant ABET data.

A writing project centered around engineering in a writing class appears to yield an excellent focal topic for a technical report; to motivate students to strive for a “best effort” and to see writing not as a separate discipline, but as something integral to their overall engineering tool kit; and to demonstrate that using so-called prescriptive, recipe-based pedagogy (sometimes frowned upon by factions within the Rhetoric and Composition discipline) does indeed work well with engineering students learning how to write reports. Furthermore, this kind of assignment contributes to engineering students’ mastery of system-level thinking and problem solving; brings a STEM component into writing program classes; and, based on the results of the assignment’s first trial, causes a flicker in the eyes of engineering writing students that this instructor saw first-hand and conjectures may be “synergy.”

References


Design Recommendation:
Automated THSMM LEGO Assembly Line

Maverick Robotics Corporation

Released: May 18, 2012

<student name removed>
SUMMARY

MRC management issued the manufacturing division to design a small-scale THSMM that automatically assembles a miniature LEGO car more efficiently and economically than a factory worker can by hand. The design team created two models of a linear THSMM (A and B). After engineering analysis and computation for the models against the baseline, we recommend Model B as the best automated alternative as it has the efficiency and cost-effectiveness of Model A with added quality assurance features.

INTRODUCTION

In preparation for the Las Vegas Automation Tradeshow, Maverick Robotics Corporation (MRC) plans to showcase a small-scale turn-key solution, high-speed, synchronous, manufacturing module (THSMM). Management has given manufacturing the task of designing a THSMM production line that automatically assembles LEGO miniature sports cars (model #9480). The objective is to design the line to efficiently and economically manufacture one million (1M) LEGO sports cars, replacing a factory worker who works a 40-hour week and is paid $18.50 per hour with a PTB factor of 1.4X.

The LEGO THSMM demo line is designed to receive a pre-manufactured LEGO car chassis. The automatic line will then proceed to complete the car with the following car parts:

- rear body panel (1)
- rear body panel trim clips (2)
- side panel trim strips (2)
- side panel trim blocks (2)
- front body panel (1)
- front body panel trim clips (2)
- cab panel (1)
- wheels (4)
The THSMM design team will evaluate the LEGO THSMM for production time, production expenses, size, and product quality/scrap rate and will post these specifications at the tradeshow. Production time and expenses will be compared against the baseline time and cost of a factory worker performing the same job. The demo line must fit within a 10-by-10 ft² section of industrial floor, while maintaining a 1-ft buffer around the edge of the floor space. Output cars must meet the quality specifications outlined in the product blueprint.

FEASIBLE ALTERNATIVES

Baseline (Factory Worker)

A standard factory worker is assumed to work a 40-hour week (8 hours per day, 5 days per week). The worker assembles each LEGO car individually by hand, with all necessary LEGO parts provided.

Model A

THSMM Model A (Figure 1) is a 6-ft, 9-station linear conveyor with go-stop-go drive and 2 quality inspection cameras located at the line input and output. All stations are equipped with one pick-and-place machine (PAPM) and one bowl feeder (BF) (see Appendix, Table A1). The line is designed to operate 24/7.

The line comprises five consecutive part-installation checkpoints (A, B, C, D, and E). As a LEGO chassis moves forward on the conveyor, it will pause at each checkpoint. Checkpoints A, B, C, and D each contain two stations that simultaneously place two separate car parts or sub-assemblies onto the LEGO chassis, and Checkpoint E places one car part onto the chassis.

Input. The THSMM line receives the bare chassis. A quality inspection camera checks that the chassis is in the correct orientation before allowing it to pass to Checkpoint A. Any chassis that does not pass quality inspection is pushed off the line for reorientation.

Checkpoint A. Stations 1 and 2 place the side trim panels and side trim blocks onto the chassis, respectively. For Station 1, the BF supplies two side trim panels at a time, automatically rotates one part 180°, and orients/spaces both parts into a sub-assembly. The PAPM then vertically lifts
the sub-assembly and places it onto the chassis top-down. Station 2 performs the analogous process for the side trim blocks.

Checkpoint B. Stations 3 and 4 place the rear body panel and the front body panel onto the chassis, respectively. For Station 3, the BF supplies one rear body panel at a time and orients it for placement. The PAPM then vertically lifts the part and places it onto the chassis top-down. Station 4 performs the analogous process for the front body panel.

Checkpoint C. Stations 5 and 6 place the rear trim clips and the front trim clips onto the chassis, respectively. For Station 5, the BF supplies two rear trim clips at a time and orients them into a sub-assembly. The PAPM then vertically lifts the sub-assembly and places it onto the chassis top-down. For Station 6, the BF supplies two front trim clips at a time, automatically rotates one part 90°, and orients the parts into a sub-assembly for placement. The PAPM then lifts the sub-assembly and places it onto the chassis top-down.

Checkpoint D. Stations 7 and 8 place the driver side wheels and the passenger side wheels onto the chassis, respectively. For Station 7, the BF supplies two wheels at a time and orients/spaces them into a sub-assembly. The PAPM then grips the sub-assembly from the side and places it onto the driver side of the chassis horizontally. Station 8 performs the analogous process for the passenger side.

Checkpoint E. Station 9 places the cab panel onto the chassis. The BF supplies one cab panel at a time and orients it for placement. The PAPM then vertically lifts the part and places it onto the chassis top-down.

Output. A quality inspection camera checks that the finished car meets the product specifications before it is released from the line. Any car that does not pass quality inspection is pushed off the line to be dismantled. The parts are then recycled into their respective bowl feeders.

Model B

THSMM Model B (Figure 1) uses an assembly line identical to that of Model A, with four additional quality inspection cameras between each pair of consecutive checkpoints. After each checkpoint, these cameras will check that the cars-in-progress meet the product specifications for that stage in the assembly before they move to the next checkpoint. Any car-in-progress that does
not quality inspection is pushed off the line to be dismantled. The parts are then recycled into their respective bowl feeders. For each car-in-progress that is removed, the following checkpoint stations in sequences will be signaled not to place car parts onto the missing chassis.

**METHODOLOGY**

The design team will use engineering analysis and computation to determine an estimated production time, expenses, and size for the THSMM LEGO lines (Models A and B) to produce 1M LEGO cars. We will use the machine part specifications, costs, and designated processes provided by management in our analysis. The results of this analysis will be compared against the baseline to prepare a final cost/time analysis.

**RESULTS**

All results obtained assuming complete production and retail sale of 1M LEGO sports cars.
Figure 1. Top-down view of Model A (blue) and Model B (blue w/ additional cameras (red))
Figure 2. Flow chart scheme of Model A and Model B

Table 1. Respective production rates and production times of the baseline worker, Model A, and Model B

<table>
<thead>
<tr>
<th></th>
<th>Model A</th>
<th>Model B</th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production Rate</strong></td>
<td>1800</td>
<td>1800</td>
<td>12</td>
</tr>
<tr>
<td>(cars/hour)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Production Time</strong></td>
<td>555.56</td>
<td>555.56</td>
<td>83333.33</td>
</tr>
<tr>
<td>(hours)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Production Time</strong></td>
<td>23.15</td>
<td>23.15</td>
<td>10416.67</td>
</tr>
<tr>
<td>(days)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Production Time</strong></td>
<td>0.06</td>
<td>0.06</td>
<td>39.91</td>
</tr>
<tr>
<td>(years)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2. Production expenses

<table>
<thead>
<tr>
<th></th>
<th>Model A</th>
<th>Model B</th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine Purchase</td>
<td>73.5</td>
<td>74.5</td>
<td></td>
</tr>
<tr>
<td>Installation</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>15</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Total Salary</td>
<td></td>
<td></td>
<td>2158.33</td>
</tr>
<tr>
<td>Car Part Expenses</td>
<td>750</td>
<td>750</td>
<td>750</td>
</tr>
<tr>
<td>Total Expenses</td>
<td>858.5</td>
<td>859.5</td>
<td>2908.33</td>
</tr>
</tbody>
</table>

Note: Thousands of US dollars

Figure 3. Comparison chart of production expenses
Table 3. Comparison of production profit figures, assuming 100% sale of all 1M LEGO cars

<table>
<thead>
<tr>
<th></th>
<th>Model A</th>
<th>Model B</th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production Profit</strong></td>
<td>8141.5</td>
<td>8140.5</td>
<td>6091.7</td>
</tr>
<tr>
<td><strong>Maximum Profit</strong></td>
<td></td>
<td></td>
<td>8250</td>
</tr>
<tr>
<td><em>(Retail Price – Part Costs ONLY)</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Percent of Maximum</strong></td>
<td>98.7%</td>
<td>98.7%</td>
<td>73.8%</td>
</tr>
</tbody>
</table>

*Note: Thousands of US dollars*

Figure 4. Comparison chart of production profit

Table 4. Production scrap rate (assumed)

<table>
<thead>
<tr>
<th></th>
<th>Model A</th>
<th>Model B</th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scrap Rate (%)</strong></td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
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</table>
CONCLUSIONS AND RECOMMENDATIONS

Production Time

From the design team’s analysis, the THSMM models are clearly more time-efficient than a baseline factory worker, completing the production of 1M LEGO cars in 23 days as opposed to 40 years (Table 1). Equivalently, the THSMM lines can produce 150M LEGO cars in the 40 years it takes a factory worker to produce 1M.

The baseline factory worker is limited by the 40-hour work week and a production rate of 12 cars per hour. In contrast, both THSMM Model A and Model B lines are designed to run 24/7 at a rate of 1800 cars per hour (Table 1). Thus, the THSMM models surpass the baseline factory worker in production rate, production time, and endurance.

Production Expenses

Performing a cost analysis on the THSMM models (A and B) and the baseline factory worker, the production expenses for each amount to $858.5K, $859.5K, and $2908.33K, respectively (Table 2). The THSMM expenses comprise the costs for machine parts and car parts, line installation, line maintenance, and power supply, all assumed to be fixed values (Table 2). The baseline expenses are defined by the cost of car parts and the baseline worker salary ($18.50/hour) multiplied by the 1.4X PTB factor and the amount of time required to manually produce 1M LEGO cars (Table 2, Table 1).

As shown by Figure 3, the costs of both THSMM models three times less than the baseline cost. Thus, to assemble the same 1M cars, using either THSMM line is more cost-effective than hiring a factory worker to perform the task.

While Model B costs $1000 than Model A, we believe its additional quality inspection cameras will maintain a better quality product, as explained below.
Size

Both THSMM Model A and Model B occupy a 5-by-6 ft² rectangular area. The line comprises one 6-ft long, 1-ft wide conveyor belt, nine PAPMs (five on one side, four on the other), and nine BF (each adjacent to its respective PAPM). Each PAPM and each BF fits into 1 ft² of space. Figure 1 shows the orientation of the line and its components as it would fit in the center of the 10-by-10 ft² section of industrial floor provided at the Las Vegas Automation Tradeshow.

Quality/Scrap Rate

Because we did not physically test the THSMM lines, we assumed a 1% scrap rate for both Model A and Model B based on the performance history of other MRC manufacturing products (Table 4). We assumed a 0% scrap rate for the baseline factory worker, reasoning that LEGO car parts are not easily damaged by hand and that the worker can manually correct any mistakes (e.g., incorrect orientation, misplaced piece, etc.) (Table 4).

While the baseline worker exhibits a lower scrap rate and, therefore, indicates higher quality assurance, the 1% scrap rate of the THSMM lines is acceptable for the LEGO assembly process and is not as significant as production time or production expenses.

The four additional quality inspection cameras on Model B will likely reduce the scrap rate compared to Model A, catching assembly errors sooner and preventing the assembly stations from placing parts onto defective cars-in-progress. In cases of defective placement, there is greater chance of part breakage if a piece is forced improperly onto the assembly. Also, detecting errors earlier will allow operators to dismantle the defective cars and recycle their pieces back into the BF sooner rather than later. However, we must proceed with empirical testing of the THSMM demo lines before making claims about this difference.

Overall

We recommend presenting THSMM Model B at the Las Vegas Automation Tradeshow. While Model B costs $1000 more, that expense is minimal compared to the profit earned, assuming all 1M LEGO cars are sold. As shown in Table 3 and Figure 4, both Model A and Model B would virtually return the same profit to the company. Thus, we feel that the $1000 expense is worth
the extra quality assurance provided by Model B. MRC is dedicated to the quality of its products, and we should emphasize that mission at the upcoming tradeshow.

Further Considerations

We must test the proposed THSMM lines to verify our analytical findings. The values for installation cost, maintenance cost, and power/energy cost are estimates. The design team will continue to research those costs to form a more accurate cost analysis as well as empirically test the line for those factors.

To further develop the THSMM LEGO assembly concept, MRC may consider designing a more versatile line, able to construct any LEGO product given the proper pieces. R&D can explore methods to program THSMM lines to accept a set of LEGO instructions (via computer) and modify the PAPMs accordingly to assemble the corresponding LEGO product.
## APPENDIX

### Table A1. THSMM machine parts and costs

<table>
<thead>
<tr>
<th>Machine Part</th>
<th>Specifications</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear Conveyor</td>
<td>• 6-ft length&lt;br&gt;• PLC unit&lt;br&gt;• Machine-vision cameras (2)&lt;br&gt;• Vacuum plumbing&lt;br&gt;• Synchronous go-stop-go drive&lt;br&gt;• Custom shuttle panel for LEGO car chassis</td>
<td>$30K</td>
</tr>
<tr>
<td>Pick-and-Place Machine (PAPM)</td>
<td>• X-Y-Z servo-powered arm and sliders&lt;br&gt;• 1-ft gripper with vacuum plates</td>
<td>$3.5</td>
</tr>
<tr>
<td>Bowl Feeder (BF) – Type 1</td>
<td>• One pick-up orientation</td>
<td>$1K</td>
</tr>
<tr>
<td>Bowl Feeder (BF) – Type 2</td>
<td>• Two pick-up orientations</td>
<td>$1.5K</td>
</tr>
<tr>
<td>Quality Inspection Camera</td>
<td>• Machine-vision camera</td>
<td>$0.25K</td>
</tr>
</tbody>
</table>