# PROBLEM-BASED LEARNING APPLIED TO STUDENT CONSULTING FOR A LEAN PRODUCTION COURSE

Sue Conger
College of Business
University of Dallas
Irving, TX 75062-4736
(214) 850-6424
sconger@udallas.edu

Richard Miller
College of Business
University of Dallas
Irving, TX 75062-4736
(972) 721-5377
rmiller@udallas.edu

## ABSTRACT

A Lean Six Sigma and Supply Chain Management, MBA-level course, averaged 15 students per semester. After several course iterations, the professor decided a change was needed because, even with in-class exercises to develop theoretical understanding, students were often unable to analogize to real-world situations. By introducing problem-based learning (PBL) the instructor sought to broaden the teaching methods, using a consulting engagement in a local food bank for the project. The food bank's warehouse had been open for six months but had already become unwieldy to manage. Evaluating and recommending changes for warehouse management provided students an open-ended and unstructured problem with goals but not means or prescribed ends, thus fitting PBL recommendations. In the course of the consulting commitment, students engaged in Gemba walks, performed several types of analyses (e.g., state, process, root cause, value chain, etc.), and identified problems and developed solutions to meet organizational goals, while applying theories and skills taught in the course.

Course readings, lectures, and in-class Lego assembly exercises provided the scaffolding for building students' mental frameworks. Then their frameworks were tested and reinforced through the consulting engagement enabling them to learn more than each alone could provide.

## INNOVATION SUMMARY

The approach is innovative in several ways. First, by coupling in-class exercises with the consulting project, students were forced to create solutions that moved them beyond the classroom, resulting in learning that could not be replicated through other classroom exercises. Second, because of food bank constraints, students had to discuss alternatives in terms of how successful each might be in the food bank environment. Thus, recognizing that compromises on the ideal solution were needed to develop recommendations that fully met the customer's needs fostered probing discussions that were unlikely with just classroom exercises. Third, course risk to students is that they fail to internalize new skills because of preconceptions. A real-world project, such as warehouse management, forces students to deal with their biases through the discussion of alternatives and what would work in a client environment, thus facilitating students' analogizing processes. Finally, real-world projects are innovative because they force discussions that might otherwise not be held. Rarely do students have the opportunity to analyze an entire warehouse operation with multiple value chains with varying needs. As a result of this project, more class concepts and potential recommendations were part for the discussions than would otherwise have been the case.

Learning Lean and the Toyota Production System (TPS) in the typical lecture format fails to transfer the richness and complexity of the topic. While this issue is relevant to many topics, Lean has one of the largest hurdles to overcome because the students typically have little, if any previous experience on which to build their contextual models. The typical pedagogical tools to overcome this problem are the use of cases studies and/or some assembly exercise, such as Lego cars. These tools provide a richer understanding of the materials, but over the years, we have observed that the applicability of the knowledge learned in the classroom often fails when students try to apply Lean and TPS in the real-world. To reduce these issues, we have added an additional stratum to the class by incorporating an open-ended problem at a local non-profit food bank. The project was selected because the problem and solution were not fully understood at the beginning, thus the students had to apply the full host of tools that they had learned in the class, as well as explore additional ones. This ambiguousness drove the students to create solutions that went beyond those in the textbook or Lego assembly, resulting in learning that could never be replicated traditionally.

## INTRODUCTION

Many full-time and working, part-time MBA students have had little exposure to the principles of Lean or the TPS. This lack of exposure is even more evident in the traditional undergraduate student whose industrial work experience is usually limited to a summer internship. Without a contextual basis on which to build, getting the students to understand Lean theory and new skills that apply that theory in a single semester are daunting tasks. Further, traditional teaching methods rely heavily on manufacturing experience and assembly techniques. For instance, classroom exercises of build some object as a way to make theory understood, such as Lego cars, kites, paper airplanes, clocks, etc. Over the past few years during which this class has been taught, the student demographics and work experience omits manufacturing, calling for a modification of the teaching style and platforms used.

The Lego car assembly approach has been used by the authors with over 80 students over the past four years with consistent success. However, from conversations with former students, while they often understood the principles, applying them outside of the classroom was often a challenge. This problem was more pronounced at the MBA level because those students who were working at the time of the course had the expectation of being able to transfer what they have learned to their jobs. Therefore, as part of course redesign, it was decided not to abandon the Lego car assembly because of the extremely positive student responses and the controlled atmosphere in which it takes place. The Lego exercises provide an active learning framework that enables the topics of the class to be reinforced through application. Also, by manipulating the conditions of the Lego car assembly processes, e.g., kitting, product variation, etc. many vital aspects of Lean and TPS are introduced and the nuances and complexity of the topics can be explored thoroughly. Thus, the foundation for future learning is in place, but the ability to apply it is still lacking.

To bridge the analogical gap between theory, case, and actual practice, a problem-based learning (PBL) approach in the form of a project for an external customer was added to the class so that students would experience the application of Lean in a real-world setting. The objectives and deliverables of an MBA-level Lean Six Sigma class, during the spring 2012 semester, were expanded to include a consulting component at a local non-profit food bank. The goal of combining these two elements of the class is to provide a basis for applying Lean principles to both the Lego car assembly and the real-world, consulting project. The unique quality of this approach is the evolution of students' fledgling, mental frameworks that are reinforced through failure and re-synthesis by their application of knowledge to a consulting situation.

## LITERATURE

Bennis and O'Toole (2005) note that students today are ill equipped to deal with complex, unquantifiable issues after they leave college. They argue that today's teaching environments fail to provide students with the knowledge of how to be 'fact integrators' rather than 'fact memorizers' (Bennis and O'Toole, 2005). To combat this issue the classroom environment has been moving beyond just lecturing and into experiential learning (Kolb, 1984). As this trend has evolved, instructors have applied new methodologies to the classroom to engage the students beyond the 'sage on the stage' model (King, 1993). A common pedagogical technique is to use case studies to expand the horizons of the classroom to include more real-world situations. However, real-world problems are best applied when the students already have some grounding in theory and its application. In addition, there are limitations to the complexity of problem that can be addressed in a classroom, regardless of how sophisticated or well-written a case study might be.

From our experience the issue of using case studies is further exacerbated because fewer students have manufacturing experience which is the typical framework in which students might have previous experience topic foundations. The students from service industries rarely have seen Lean concepts and they have less comprehension of the process in which the concepts work and the wastes that exist in service jobs.

Thus, when teaching Lean and TPS concepts, the case study method is a poor choice because students lack the both physical and conceptual foundations. In addition, as with many other fields, there are several other skills objectives for applying Lean that need to be learned, such as value-added analysis (VAA) and root cause analysis (RCA), and teaching these skills from a book is difficult, if not impossible.

To counteract this lack of contextual foundations, Lean classrooms have used Lego car assembly for a number of years; Lego builds are also used by many consultants in training (Rosen & Rawski, 2011). From a fundamental standpoint Lego cars are a much more effective medium to convey the basic aspects of Lean and TPS, but the level of Lean complexity demonstrable through Lego builds is limited because classroom scalability does not support all of the interdependencies with implementations that might be explored.

A similar issue has been encountered in medical schools that found that the traditional lecture model failed to impart the contexts and interdependencies that doctors encounter (Donner & Bickley, 1993). Problem-based learning (PBL) was developed to help the students understand medicine from a more holistic viewpoint (Schmidt, Rotgans, & Yew, 2011). Two distinguishing aspects of PBL, from the instructor's perspective, are the open-endedness of the problem and the lack of direct guidance (Hmelo-Silver, 2004). The second, and probably most difficult for the typical instructor, is the change in their role from direct guidance to tutoring. PBL uses tutors or coaches that are available when the students need assistance. However, tutoring assistance is not to 'teach' but to clarify ideas, and review the thought and task processes. The student's job is to identify what they don't know, find the pertinent information, and teach themselves.

In conjunction with tutoring, the instructors role is to help provide the students with *scaffolding* (Hmelo-Silver, 2004) that acts as a support mechanism around their exploration of the topic they are trying to learn. Scaffolding is the theoretical, skill, and practical application of theory relating to the problem area for the PBL exercise (Hmelo-Silver, 2004). PBL problems are recommended to be ill-structured, not have a single correct answer, and have the information to solve the problem unavailable at the outset. Thus students need to iteratively work towards a solution (Hmelo-Silver, 2004).

In addition to the problem characteristics, one of the key components of PBL is the understanding of what the problem solvers do not know and how to acquire the knowledge. This knowledge gap is one of drivers of the learning process because the students must frequently revisit their assumptions and hypotheses about the problem, state of current information about the problem, frame and reframe the problem as necessary, ask the appropriate questions, and assess the knowledge gap again. This iterative process reinforces the tenets of Lean and TPS better than can be accomplished in a classroom environment.

## Innovation

Within the limitations of case studies in Lean, our innovation couples the experiential learning of the Lego cars with a PBL consulting problem. By utilizing the Lego cars to teach the basic aspects of Lean in a controlled environment, the students develop a base of knowledge that can be applied to a real-world problem. While neither of these individual components (Lego + PBL project) is innovative alone, when combined as a whole they provide a synergy of learning that far exceeds what a full semester of either technique alone could accomplish.

As Bennis and O'Toole (2005) warn, today's students are leaving college of businesses without the core ability to apply their knowledge sets to complex problems. By providing our students with the application of the principles of Lean using a PBL approach, they have experience with a 'messy' problem and have developed a toolkit that will allow them to apply Lean principles most any setting that their careers encompass.

Using live projects as a teaching approach is not without risk to the professor because it requires significant improvisation in dealing with both the client and staff at the project organization, and the students in the live situation. The risk to students is that they come with preconceptions that they cannot grow beyond to apply new skills to the project. This is more likely with classroom-only exercises because students can conclude the exercises successfully while failing to analogize to work situations. A real-world project forces students to deal with their biases through the discussion of alternatives and what would work in a client environment, thus facilitating students' analogizing processes.

Real-world projects are innovative because they often force discussions that might otherwise not be held. While Lego exercises provide discussion and understanding of complexity, the need to compromise for a given context or requirements is missing from that type of learning. This particular combination of Lego + PBL project was innovative because rarely do students (or professors) have the opportunity to analyze an entire warehouse operation with multiple value chains with varying needs. As a result of this project, more class concepts and potential recommendations were part for the discussions than would otherwise have been the case.

Client management and project management are skills that often are not taught because of course constraints. As a result, of live projects, students gain these valuable skills as well as the typical alternatives analysis skills from the in-class exercises.

## IMPLEMENTATION

### Lego Car Assembly

The Lego car assembly has been used by the authors for the past four years in a variety of mixed undergraduate/MBA and MBA classes. The following description is for one MBA classes, but the basic structure differs little from the mixed classes.

The purpose of the Lego car assembly exercises in the classroom is to provide a stable environment for students to begin to understand the basic principles of Lean. The Lego car, seen in Figure 1, is used throughout the semester with variant models introduced in the later part of the semester with two of the 13 variations shown in Figure 2. The students are assigned to groups of 5-6 students and divide the work among a group of material handlers and assemblers. The students' goal is to build as many cars as possible in an 8 minute build with as little excess inventory as possible. The exercise is summarized in Appendix A. They main metric for each 8-minute build is the total revenue from each completed car less the costs of materials, labor, and left over inventory. An example of the scoring sheet is in Appendix B. The team with the most revenue is the 'winner'.

Figure 1 – Typical Configuration

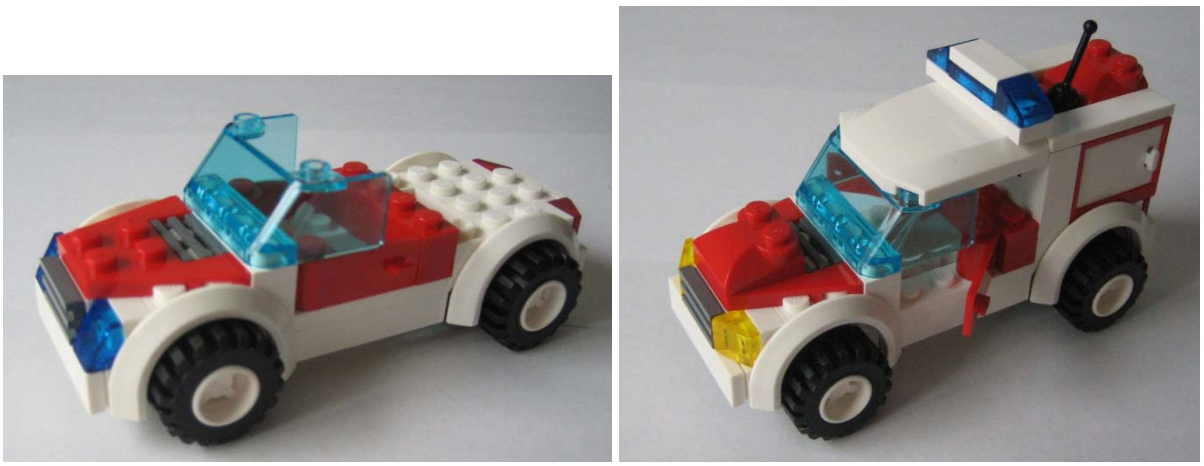

Figure 2 – Variant Designs (2 varients out of 13 total)

During the first several weeks of Lego builds, the students begin to 'see' the wastes in their systems and apply the principles of Lean learned in readings and lectures to their assembly process. Their typical learning points are: flow, waste identification, push vs. pull, work balance, and achieving single piece flow, takt time development, kanbans, visual factory, quality at the source, and quick changeovers when variations are introduced (Dennis, 2007; Naylor, Naim, & Berry, 1999; Shahram & Cristian, 2011). These learning points are detailed in class lectures and readings, which are structured to occur at approximately the same time that the students typically experience those problems in their Lego builds.

The typical configuration builds take place for approximately two-thirds of the semester, which is about the time it takes for students to begin to master the process. Then, 13 variants of the model are introduced to 'break' their systems and force them to redesign their process to accommodate the variation. This creates a knowledge gap that they work at overcoming for the remainder of the semester. As a note, they are warned after the first build in the second week of the semester that the variation will take place and that they should be designing their systems as such. Some of the variations are as slight as the head lights swapping colors with the light bar and some are radical, for instance, a requirement that finished cars use 50% of the parts used previously. Variation from design changes causes the students' systems to be placed under the maximum pressure to force a failure and a subsequent correction. As is often said by the Professor, "Only when you break something, fix it, and keep it fixed are you sure that you have made a better system."

It must be noted that the most difficult issues for every group are information flows and communication. At the beginning of each semester, students expect the physical assembly of the cars to be their top issue, but they are warned repeatedly that this is a minor issue and that they need to focus much more effort on their ability to transfer information. Invariably, about half way through the semester, they realize that without information, the best assembly systems are useless unless they know what they are building and what everyone around them is doing. More is said about this point during the PBL portion of the paper.

To reinforce the learning process, each individual and each team submits written reflection papers on the Lean issues that they learned and what needs were to be addressed for each build. This task makes the conceptual aspects more explicit by codifying the issues. Also, shortly after the builds begin, there is a lecture on root cause analysis and the students must also include a minimum of one RCA for each of their reflection papers. It has been noted that the typical student has little understanding of the difference between symptoms and causes, so this exercise gives them a tool that remains useful throughout their careers.

**PBL Consulting Assignment**

The PBL consulting assignment took place at a local non-profit food bank that consolidates food donations, sorts and segregates the donations, and then distributes them to local food pantries and soup kitchens. This project was selected because it had some ambiguous and poorly defined aspects of the food bank's inventory control, warehousing, and food distribution processes. The food bank understood that their internal processes were not adequate, but had little understanding of how to proceed in fixing the problems. From a PBL perspective, this situation was ideal because the client did not know the information, nor did they have the knowledge about what was needed to fix the problem. This met the criteria of both Bennis and O'Toole's (2005) complexity and ill-defined problem and PBL's open-ended solution. Because of these conditions, the students had to complete several cycles of assessing their knowledge gaps and obtaining the necessary facts.

The students were broken into two groups to work on two separate but related issues: warehousing -inventory management and the food donation sorting process. Breaking the problem into two sub-projects insured that the teams had adequate time to complete their projects and not be overwhelmed by the scope of the food bank problems.

As stated previously, the instructors had to shift their mind set from being the 'sage on the stage' (Donnelly, 2006; Hmelo-Silver, 2004) to become a tutor in the process. It would be easy to jump into the learning process and show the students a solution to the problem, but this short-circuits the PBL process and does not allow the students to learning in their own way. The most frequent tutoring item was helping the students identify their knowledge gaps and assisting them in developing strategies to close the gaps. At the beginning of the projects, most of the students had never been in a warehouse or involved in a sorting process, beyond a tour, and did not know enough about the situation to understand which questions to ask.

**Effectiveness and benefits of the learning approach**

The goals of our approach were to provide a mechanism to transfer the learning taking place in the classroom to a complex and ill-defined problem in the real world. Conducting the PBL project without the scaffolding of the lectures, readings, and Lego car assembly would have been more difficult and less rewarding to the students. The learning outcomes and the resulting scaffolding were effective as, in the words on one of the students, “the projects were useful and completely related to the course material since the key to maximizing profits is to minimize waste, which is the basic principal of lean.”

The Lego car assembly and the PBL project were concurrent activities. Following the guidelines of the PBL method, the professors did not give solutions during the visits to the food bank. However, the principles of Lean are universal and are easily transferred from one setting to another. Therefore, during the Lego builds potential solutions would be subtly reinforced to nudge the students into seeing the boundary spanning solution. Class concepts reinforced during every build and during class lectures related to the need for accurate and timely information flows, using the KISS (Keep It Simple Stupid) principle in developing solutions, and designing solutions that act on information while it is being created or known.

Continuous reinforcement created a drumbeat of these items that became apparent during the later visits to the food bank. During one visit, a student had the observation that the problems that they were trying to grasp were the exact same problems that they were trying to solve in the Lego builds. The issue evolved around how to use visual communication during the variation builds to let the assemblers know what vehicle they are building. The solution that was developed was to color code each of the variations and all subsequent items, e.g., training documents, kanbans, etc. The sorting area of the food bank had the same issue in that multiple varieties of foods that could be identified using the same solution. Once this watershed event took place, the students began to see that the solutions for one context could be the solution for the other. See Figure 3 and 4 for an example of the crossover.

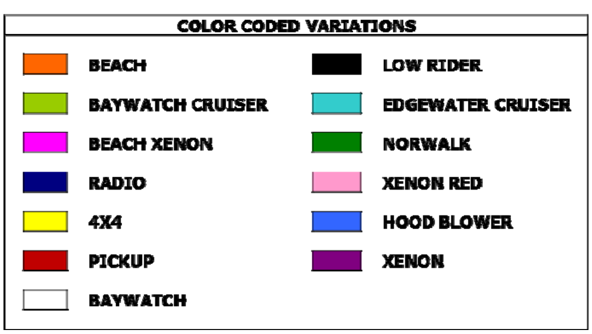


Figure 3 Color-coded Sheet for Lego Variations


Figure 4 Color-coded Sorting at Food Bank

Another key learning point for the students related to how the complexity of applying lean to a larger scale results in waste still being in the system. One of the teaching points during the Lego builds is that a system will rarely be in perfect balance, but with a small system, it can come close. In the food bank, the complexity quickly made any attempt at balance a quixotic endeavor. However, this lesson was hard for students to grasp because from their success in the Lego builds, and applying the color coding to the sorting area (see Figure 4); they thought that most other learning points would transfer as well. With tutoring, they were eventually able to identify the key bottleneck operations at the food bank and design solutions to ensure the waste in these areas was minimized while the waste somewhere else was unchanged or could increase; thus, a local increase of waste in one area could lead to lower overall waste in the warehouse.

A critical tenet of theme of the class relates to information management and the ability to transfer information during hand-offs. A lack of appreciation for information management repeatedly drives difficulties during the Lego builds and the students struggle with it. During the second visit to the food bank, one student who had been performing root cause analyses about this problem with his Lego team made the comment, “This is just like the Lego cars on a larger scale.” His realization led to a solution at the food bank for the labeling of the inventory to maintain integrity during transfers to the warehouse. This solution created scaffolding from the food bank back to the classroom because the student successfully transferred the solution to their Lego builds. This outcome was extremely encouraging about the effectiveness of learning as the students became aware of the applicability of their new knowledge.

**Evaluation Plan**

The evaluation of projects included on-site reviews, group discussions, individual reports, and client acceptance of solutions. The first phases of evaluation included on-site review meetings and group discussions. To gather information, the students visited the food bank five times, conducting Gemba walks, mapping the operations, and interviewing the staff. During the visits, the students identified their knowledge gaps and consulted with the instructors, who were present at all of the visits, for necessary tutoring. During each visit, students discussed potential solutions, reevaluated their assumptions and knowledge, and collected more information. These iterations allowed for critical analysis of the recommendations for their adequacy in meeting the food bank’s specific needs. The professors monitored progress of the iterations to ensure that progress towards the project’s completion was being made.

The second phase was individual reports based on group and individual student recommendations allowing everyone to present their own unique perspective and ideas (See Appendix C for structure and deliverables of these reports). After the reports were graded, a group discussion was held to discuss the best ideas from each student and create a unified solution to the problem. Selecting this order of submission created more work for the instructor, but the quality and creativity was better than a single report was likely to generate. As a note, the two-step reporting process was chosen to allow each student to have a voice and keep the dominate student(s) from having to great an influence. During this phase of the project, the solutions generated in the individual reports, when aggregated, improved over their recommendations generated during the food bank visits.

The last test of project effectiveness was the client accepting and implementing the recommendations. The final report-out to the management of the food bank was an unqualified success as the entire set of student recommendations was agreed to enthusiastically and scheduled for implementation. The effectiveness of the students' impact on the food bank was evident during the later on-site sessions as they noticed that the preliminary recommendations that had been reviewed with the floor personnel and management already had been implemented. From the students' perspective, these implementations were the most sincere complement that they could have received by seeing that their ideas had value and were helping the food bank to improve its operations.

### Educational objective success

As stated above, the educational objectives was to create scaffolding from the classroom to the PBL project utilizing Lean Six Sigma, 5S, DMAIC, VAA, RCA, etc. This objective was met as evidenced by the students' ability to transfer their accumulated knowledge from the classroom to the food bank setting. The success of this classroom innovation exceeded the initial objective of improved student integration of material as evidenced by the implementation of the complete set of recommendations. The underlying objective, though not explicitly stated at the outset, was to engage the students in a project that provided them with the opportunity to apply their knowledge and create a passion for the topic as evidenced by the comments from a student, "This (the food bank project) was useful and really helped in learning how to apply the material."

## Transferability and Implications for Educators

The coupling of the synergistic aspects of controlled experiential learning in the classroom and applying the learning in a PBL-based project has many applications outside of Lean. Our experience reinforces the use of scaffolding or other appropriate frameworks through which students can learn in the relative calmness and stability of a classroom. Then, given the selection of a project that is properly complex, the students can combine these two learning environments to learn more effortlessly to apply theory to practice, adjusting for contextual specifics.

Anecdotally, most projects outside of the classroom are selected because they are well contained or have a small solution space for potential outcomes to the problem. This type of project can be selected for many reasons: 1) there is a fear that the students won't be able to find a solution to the problem, 2) ill-defined problems will be difficult to solve, or 3) it is easier to teach during the project than to act as a tutor. Before this project and the success that was found, many of these arguments held as we worried about these same issues. But, after seeing the success of the scaffolding of the classroom to the PBL project these fears have been alleviated.

Two important caveats must be made about the selection and management of the projects to use: scale and scope. The complexity of the problem and the potential solutions must be closely coupled to a written statement of work because it is very easy to confuse the scale and scope of work. For example, while originally negotiating with the food bank, we had agreed on the two projects described above. At outset of the negotiations they wanted the project to include the coordination and communication between two facilities, but with the limited amount of time, enrollment in the class, and time required for the students to direct themselves through the numerous knowledge gaps they would face, there would not be enough time to complete that project. The complexity of the solutions in one of the facilities was adequate for the needs of this project. So, care in project definition is required to meet pedagogical goals while also solving client problems but without committing to trying to solve all client problems in a single semester.

The second caveat deals with expansion of the scope of work, often referred to as mission creep. During the first several weeks of the project the students were suggesting solutions to the various issues and the management of the facility realized the value of the project. They asked for the project to be expanded to another area of the facility that was experiencing similar problems. However, this request was turned down for two reasons: time remaining in the semester and more importantly, the students were succeeding and it was decided that the additional scope could jeopardize both their learning and the quality of the project outcome. If the scope is too large, student stress reaches a point at which they get frantic to get to solutions rather than trying out different ideas from the class to see which might apply and how. As with any project such as this there is always the desire to please the client for a variety of reasons, but the ultimate goals are the student learning and quality of client outcomes. Therefore, both scope and scale need to be balanced and managed by the professor in developing project definitions that optimize student learning.

## SUMMARY

This paper describes the use of problem-based learning for MBA-level course and its application. The course taught Lean Six Sigma and Toyota Production Methods, including Gemba walks, root cause analysis, value-added analysis, definition of inventory models, push-pull inventory management techniques, and information management. The goal of the projects was to provide a means for students to learn how to analogize from classroom learning to practical situations. By using readings, lectures, and in-class, Lego-build projects as scaffolding, the students performed a consulting engagement with a local food bank as a PBL exercise.

The project outcomes were successful for students who were able to apply theory to practice, and critically evaluate and compromise on solutions that fit the context. As a result of the PBL project innovation, students engaged in discussions they would otherwise not likely had and were able to successfully develop solutions for warehouse management of the food bank. We recommend this approach to other professors teaching relatively abstract subjects to greatly enhance their students' learning.

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## APPENDIX A – LEGO PROJECT DESCRIPTION

OPER 7373 Project Descriptions, Spring 2012

### Lego Competition

During the course of the semester, we will be using the Lego assembly as a hands-on learning exercise about the principles of lean. During the course of the project we will have a variety of assignments and activities stemming from it.

During/after each run you need to collect the following data at a minimum:

- How many people assembled, handled materials, collected data, etc.
- Total pieces produced
- Total WIP (see WIP form), cost, where in process
- Detailed quality issues (assembly, material handling, where in process)
- Changes made to assembly, flow, # of people, material handling, etc.
- Disassembly times

### Components of the Lego Project

1a. **Reaction papers (Individual) –** As we progress through the project, each time we have an in-class component of the project, you each will be required to turn in a 2-3 page (double spaced) reaction paper that covers the following items:

- Observations during the exercise
    - What was the lesson that was learned during the exercise?
    - What specific components of lean came out during the exercise?
    - During the next exercise, what would you do differently based on the lessons learned?
        - This needs to be specific action items
    - Any other observations, improvements, etc., for the next round
- Use of root cause problem solving for at least one issue per build (to be included after Root Cause Lecture)
    - This will be in the form of a 5 Why

Note: I don't want a recap of the data from each person: include this in your team report. You are welcome to include the data as it makes a point or illustrates the recommendations that you are making.

**This paper will be due by Monday at 8:00 am** (There is a drop box on eCompanion for each build)

1b. **Reaction Paper (Team) –** Each team needs to submit an executive overview of:

- Basic information on performance (not limited to the following):

    - Number of vehicles built and variants
    - Disassembly quantity and time
    - Total profit/loss per round
    - Major issues for the build
- Detailed action plan for next build that is the consensus of the team; hence, why you submit a single team paper!!
    - Who, what, when, how

**This paper will be due by Tuesday morning at 8:00 am**

- One representative from each team will e-mail this paper to me and cc the rest of the team

2. **Analysis of the Project –** During the project you will be analyzing the progress that is being made on implementing lean. We will cover a variety of tools that you can use to analyze the project and plan for its improvement. Keep a team folder of all of your team meeting notes, team reflection papers, data, etc. This will serve you well as you write item #3. I recommend that you create a data keeper to manage this data set.

3. **Lean Report –** You will turn in a single-side A3 report (11"x17"). All of your critical information must be contained on the report of what you have learned, implemented, and results of improvements. (Warning, using small font for the report is not an option. All text must be at a minimum, 10 pt Times New Roman/Arial.) You can have supplemental materials and appendices, but these materials cannot be used during the presentation of the report.

Project Issues to be factored into the analysis

1. The task was to build a car from 40 different parts.
2. Car parts should be kept in a separate place (inventory) while car assembly is done in different table (factory).
3. Each part has a value which is doubled when moved to the assembly table if the car was not built successfully. However, teams would make profits if they managed to build full cars.
4. The group can allocate people as material handlers, assembler, or both. Each worker has a wage that is added to the overall cost, i.e., material handler $3000, assembler $5000, and combo (material handler and assembler in the same time $8000).
5. To improve the flow, teams have to come up with a system and improve continuously, e.g., using visual aids to minimize missing/extra parts.

# APPENDIX B – LEGO CAR ASSEMBLY REVENUE AND COST SHEETS

WS - Inventory in Work Station WIP - In process Inventory (Assembled in any way)

| Part | QTY | Picture | Assembly Step | Color | Cost | Total Cost per Car | | WS1 | WIP1 | WS2 | WIP2 | WS3 | WIP3 | WS4 | WIP4 | WS5 | WIP5 | WS6 | WIP6 | WS7 | WIP7 | WS Inventory QTY | WS Inventory Cost | WIP Inventory QTY | WIP Inventory Cost |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Axles | 2 |  | | Grey | $500 | $1,000 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Axle Sub-plate | 2 |  | | Black | $250 | $500 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Chassis | 1 |  | | Black | $2,500 | $2,500 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Front grill | 1 |  | | Grey | $175 | $175 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Top grill | 1 |  | | Grey | $150 | $150 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Hood | 1 |  | | Red | $500 | $500 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Front/Rear Sub-Bumper | 2 |  | | White | $400 | $800 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Front & Rear Bumper (large) | 2 |  | | White | $150 | $300 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Rear Bumper (small) | 1 |  | | White | $100 | $100 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Rocker Bar | 2 |  | | Grey | $375 | $750 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Windshield | 1 |  | | Blue | $800 | $800 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Roof | 1 |  | | White | $500 | $500 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Roof Support | 1 |  | | Black | $250 | $250 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Door (Right & Left) | 2 |  | | Red | $400 | $800 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Steering Wheel | 1 |  | | Red/Black | $350 | $350 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Rear Seat | 1 |  | | Red | $125 | $125 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Cargo Box Support | 1 |  | | White | $100 | $100 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Cargo Box Support Post | 2 |  | | White | $50 | $100 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |

| | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cargo Box | 2 | | | Red | $475 | $950 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Cargo Box Door | 2 | | | White | $150 | $300 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Carbo Box Cap | 2 | | | White | $75 | $150 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Base radar upper part | 1 | | | Red | $150 | $150 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Fender | 4 | | | White | $225 | $900 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Antennae | 1 | | | Black | $100 | $100 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Wheel | 4 | | | Grey | $160 | $640 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Tire | 4 | | | Black | $250 | $1,000 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Top Light Cap | 1 | | | White | $75 | $75 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Red Light Wedge | 2 | | | Red | 50 | $100 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Blue Light Bar | 1 | | | Blue | 50 | $50 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| BelowRoof Support | 1 | | | Blue | 50 | $50 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| Blue Light Wedge | 2 | | | Blue | 50 | $100 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |
| YellowLight Wedge | 2 | | | Yellow | 50 | $100 | | | | | | | | | | | | | | | | 0 | $0 | 0 | $0 |

$0 $0

Raw Material
$14,465

WIP Factor
50%

Labor Costs (per build) | | # of each | Total Labor
---|---|---|---
Assembler | $5,000 | 0 | $0
MH | $3,000 | 0 | $0

Total Number Built
0

Revenue per
$ 25,000

Total Revenue
$0

Total Cost
Raw Mat'l $ -
WIP $ -
Labor $ -

Total Revenue $0

Other

$

## APPENDIX C – PBL PROJECT REPORT DESCRIPTION

**Implement Lean Six Sigma Report**

Complete a minimum 12 page paper (Title, Bibliography, etc. do not count in page total) on the following:

Note: Process maps count as 1 page each (These can be hand drawn, but must be professional looking)

To be included in the paper:

- Description of what the process is and how Lean Six Sigma is a fit
  - Measurement and analysis of the problem that shows that you are treating root causes and not symptoms
- Current process state
- Ideal process state map
- Improved process map (map to be implemented)
- Identify the waste streams (people, process, inventory, etc.)
  - This class is also about supply chains, so identify supplier and customer issues
- Sources of variation and how to reduce them (this is the focus of the paper, so a large portion should be focused on this section) - DMAIC
  - Concrete and explicit ways to implement lean
  - Specific implementation plan
  - How to monitor and control the improvements
    - Short-term and long-term…They are different so have specifics for both
- Potential issues and/or barriers to implementation (personnel, training, layout, system, process, etc.). What can be done to overcome these issues?