Capstone Design Progress Report
Sigma Cell

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EXECUTIVE SUMMARY

The goal of the Sigma Cell project is to install a manufacturing line and integrate a work cell that effectively demonstrates lean-manufacturing techniques. The work cell will be a PLC (programmable logic controller) controlled pick-and-place device with interchangeable end-effectors. The design will be such that SMED (Single-Minute Exchange of Die) techniques, including design improvement and organizational improvement, are easily measurable and tested.

Most of the effort for the project has been involved with preliminary research. Once donated manufacturing line equipment is received (courtesy Hewlett Packard, Boise), the equipment will be inspected, installed, and set operational in a UI Boise laboratory. After equipment capabilities are observed, a detailed set of requirements and specifications will be created for the work cell. Conceptual design work is estimated to begin in mid-February, 2005; and estimated project completion is mid-June, 2005.
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1 BACKGROUND

In the spring of 2004, Hewlett Packard, Boise, agreed to donate used Bosch manufacturing-line equipment to the University of Idaho. This December, the equipment will be delivered to the Product Development Laboratory of the new Water Center Building at UI Boise. After the conveyor is installed and functional, two work cells will be specified, designed, constructed, and integrated into the conveyor. Bryan Pepper will be responsible for the "lean manufacturing" work cell; Mr. Charlie Ford, a UI graduate student, will be responsible for the "Six Sigma" work cell. The entire project is under the direction of Dr. Larry Stauffer, professor of mechanical engineering at the UI Boise campus. The work cells will serve as an educational aid for UI graduate students by demonstrating the concepts of Six-Sigma and Lean-Manufacturing techniques.

Six Sigma and Lean are two statistically-driven techniques for reducing defects, decreasing downtime, and optimizing process flow. Companies such as Toyota, GE, Honeywell, Motorola (and the list goes on...) have adopted one or both of the techniques with great success. The payoff is reduced manufacturing costs, increased profits, better product, and satisfied customers. Both techniques are great educational assets to students, and the UI Product Development Laboratory will provide the tools necessary for an applied understanding of Six Sigma and Lean Manufacturing.

To eliminate confusion, my senior design project was originally set to demonstrate six-sigma concepts—thus the name “Sigma Cell”. However, the scope was changed in November, 2004, and my goal is now to produce a workcell capable of demonstrating lean manufacturing technique(s). However, the name of the project will remain as “Sigma Cell”.

2 PROBLEM DEFINITION

2.1 Goal

The goal of the Sigma Cell Project is to (1) install and document a donated Bosch manufacturing line, (2) develop a manufacturing work cell that will effectively demonstrate lean manufacturing techniques, and (3) integrate the work cell into the Bosch manufacturing line.

2.2 Fundamental Requirements of the Workcell

Once the donated work cell and conveyor are obtained, the equipment will be modified to some extent to meet the specific requirements of the Sigma Cell project. Note that detailed requirements will not be created until after the equipment is received and examined. Dr. Stauffer and Mr. Ford will then set requirements on how the cell should function. A detailed requirements list, constraints list, and specifications will then be created.

Thus far, only a limited amount of requirements have been generated. They are as follows:

- Cell must demonstrate the a lean manufacturing concept—preferably SMED (Single Minute Exchange of Die)
- Actuator must be a cartesian style "pick-and-place" device
- Entire system must be controlled by a PLC (programmable logic controller)
- Actuator must have a minimum of 2 degrees of freedom, with 3rd degree achieved by conveyor
- System must be capable of utilizing 2 attachments (end effectors)
- Basic operational parameters must be adjustable via a simple user interface

Listed below are some general constraints:

- Must make use of equipment provided (donated). No major components will be purchased
- No end-user PLC software access of manufacturing cell. Simple user interface must be provided instead
- Components must be 24 VDC
3 DESIGN

3.1 System Architecture

The heart of the Sigma Cell design is a pick-and-place actuator. The actuator will be part of a donated work cell that contributed to manufacturing ink cartridges for Hewlett Packard printers. Because I have not seen the equipment to be donated, its exact function is unknown. But through meetings with Hewlett Packard personnel, the basic architecture of the work cell was described. The bulleted list indicates some key points:

- The motion system will likely be cartesian style and operate in two dimensions. It will be manufactured by Rexroth, and it will look similar to the photo in Figure 1.

  Figure 1. Rexroth Twin-Axis Actuator

- The motion system will have a gripping device (end effector) attached for handling a specific part. The end-effector will likely be replaced or modified to handle the future requirements of the Sigma Cell project.

- Servo motors with screw drives will provide orthogonal movement, and the end-effector will likely be controlled with pneumatically powered linear actuators.

- The servo motor behavior will be controlled via a programmable motor controller with position feedback. The make/model of the motor controller is unknown at this time.
• Overall function of the workcell will be controlled via an Allan Bradley SLC-500 Series programmable logic controller (PLC). Furthermore, the PLC will control a Bosch TS-2 conveyor system. See Figure 2.

Figure 2. Allen Bradley SLC-500 PLC

The PLC is completely modular, and it has bays for a power supply, communications module, and a large selection of I/O modules. I/O modules include digital input, digital output, analog input, analog output, and mixed signal styles.

• Ferromagnetic, capacitive, sonic, or infrared proximity sensors will provide additional position information to the PLC.

• A third dimension of movement will be provided by a Bosch TS2 recirculating conveyor similar to the photo in Figure 3.

Figure 3. Typical Bosch Conveyor
• The conveyor will have future work cells integrated into it. Therefore, electrical connections to the conveyor must be designed such that electrical connections from future cells are easy to connect.

Figure 4 illustrates the overall layout and connectivity of the Sigma Cell System.

Figure 4. Sigma Cell Overall Layout
3.2 Design Approach

The overall design goal of the Sigma Cell Project is to produce a manufacturing workcell capable of demonstrating lean concept(s). Lean concepts cover all facets of a business, but because the project will be built from manufacturing-line equipment, only lean manufacturing techniques are considered. SMED (Single-Minute Exchange of Die) is one relevant lean technique that deals with minimizing downtime during tooling modification. (See Section 5 for more details on SMED.) To demonstrate SMED, the workcell could have two removable end-effectors—each for two different products. In this case, the “products” are two groups of objects (Group A and Group B). One end effector can only handle Group A products, and the other end effector can only handle Group B products.

A palette with Group A products could be loaded and sent down the line. After the stop gate is tripped, the pick-and-place device could then start removing the product from the palette and place the items on a tray. Midway through the process, the workcell could be stopped and transitioned to work with Group B products. This would require changing the end effector and the cell’s operational characteristics. The goal for a group of students would be to perform a changeover and record the duration. Next, students would be required to figure out ways to minimize downtime using SMED concepts. The transition from Group A products to Group B products would be repeated with SMED optimization techniques in place. The changeover duration would again be measured—hopefully with some improvement gained.

Parameters foreseen as adjustable by students include PLC software parameters (via a hardware interface), end effector design, and handtools necessary for changeover. These items would fall under “design improvements”. Likewise, “organizational improvements” (including parts retrieval, task order, task allocation, workforce, etc.) could be altered to create gains in changeover efficiency. Exactly how these variables are to be implemented on the workcell will be determined in January, 2004, after the equipment has been received and inspected.
4 FUTURE WORK and TIMELINE

During the final week of December, I will be moving down to Boise, ID for work at Micron Technology. By this time, the Bosch conveyor and pick-and-place workcell should be received by UI Boise. I will have two days a week allocated to this project. My first major goal is to study the manufacturing line and workcell.

Next, the manufacturing line will be installed, set operational, and adjusted via the PLC. During this time, I will also attempt to control the workcell with the servo-motor controllers. The capabilities of both devices will be observed and demonstrated—from which Dr. Stauffer and Mr. Charles Ford (UI mechanical engineering graduate student) will then generate detailed requirements for me.

At this point, estimated completion of the project is in mid-June, 2005. A task list is shown in the table below:

Table A. Task List

<table>
<thead>
<tr>
<th>TASK</th>
<th>DURATION</th>
<th>TIMEFRAME</th>
<th>COMPLETE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PHASE 1 - Project Scoping and Team Selection</strong></td>
<td>18d</td>
<td>Tue 11/9/04 Thu 12/30/04</td>
<td></td>
</tr>
<tr>
<td>Schedule meeting times/locations</td>
<td>1d</td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Assign team goals/roles/responsibilities</td>
<td>0.25d</td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Create system for organizing team documents</td>
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<td></td>
<td>100%</td>
</tr>
<tr>
<td>On site customer interview</td>
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<td></td>
<td>100%</td>
</tr>
<tr>
<td>Project status reports</td>
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<td></td>
<td>50%</td>
</tr>
<tr>
<td>Problem statement</td>
<td>0.25d</td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Constraints list</td>
<td>0.25d</td>
<td></td>
<td>50%</td>
</tr>
<tr>
<td>Preliminary research (lean, six sigma, DOE)</td>
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<td></td>
<td>50%</td>
</tr>
<tr>
<td>Objective tree</td>
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<td></td>
<td>0%</td>
</tr>
<tr>
<td>Web page development</td>
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<td></td>
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<tr>
<td>Equipment inspection</td>
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<td></td>
<td>10%</td>
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<tr>
<td>Create detailed cell requirements</td>
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<td></td>
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<tr>
<td><strong>PHASE 2 - Conceptual Design</strong></td>
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<tr>
<td><strong>PHASE 3 - Preliminary Design</strong></td>
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<td>Fri 2/25/05 Fri 4/15/05</td>
<td>0%</td>
</tr>
</tbody>
</table>
5 RESEARCH

5.1 Overview

So far, the majority of effort for the Sigma Cell project has been involved with research. Section 5 is dedicated to the preliminary research performed to date. Research has been focused on lean manufacturing.

5.2 Lean Manufacturing

Lean manufacturing is composed of statistically-based methodologies that reduce waste in manufacturing, accounting, marketing, sales, procurement, shipping, storage, and service. Waste can take the form of material, time, and resources. The goal of lean manufacturing is to improve processes and business structure such that waste is minimized and profits are maximized.

I am currently researching lean manufacturing principles and how those principles apply to a manufacturing line. Because this project involves a manufacturing line, only the lean techniques that apply to production processes are considered. In particular, production can be improved by reducing downtime during tooling changes via the SMED technique. A description of SMED thus follows in Section 5.3.

5.3 SMED

5.3.1 Need for SMED

In today’s manufacturing market, businesses are striving to find ways to become more efficient. Without an operational edge, most manufacturing facilities cannot remain competitive, and the result is lost sales and potential shutdown. The fierce competition is a direct result of increasing customer demands. Several factors attribute to this trend. One such factor is a demand for customized (personalized) product. Historically, manufacturers have created more generalized products that satisfy most customer needs. This approach is becoming less popular. Now, customers desire more choice in the products they buy. Clearly, any business that can manufacture products that satisfy individual customer requirements will hold a competitive advantage.
Another factor driving increasing customer needs is technology itself. A large intellectual effort within society is placed on the advancement and implementation of electronics technology. As a result, chip densities are growing exponentially. This trend was predicted nearly 40 years ago by Intel co-founder Gordon Moore. He forecasted the rapid pace of technology innovation and created Moore’s Law. Moore’s Law states that the number of transistors on a particular die will double about every two years. This trend has been holding true since the 1970’s. Additionally, electronics are—to some extent—integrating into nearly all the products we buy. As a result, products must be continually updated to keep up with the latest technological trends.

To remain competitive, businesses must reduce lot sizes and minimize inventory. Stocked goods quickly become obsolete, and inventory creates expensive overhead costs. Furthermore, cycle-time must also be minimized so that new products fulfill customer demand as quickly as possible. The solution is rapid tool changeover via the SMED (Single Minute Exchange of Die) technique. The goal of SMED is ready a tool for new product in less than ten minutes (“single minute” means that setup time is counted on a single-digit).

5.3.2 The Changeover Process

In order to explain SMED, the changeover process must first be explained. A changeover is the complete process of changing between the manufacture of one product to the manufacture of an alternative product. Figure 5 on page 11 illustrates the changeover phases as well as the effect on line output.
Figure 5. Line Output During Changeover

The total elapsed changeover time, $T_c$, consists of three phases: (1) run-down period, (2) setup period, and (3) run-up period.

The run-down period is the time between the end of full production and the point at which the line is completely stopped. For some manufacturing lines, the run down period is zero; thus, the machine can be instantly halted for changeover. In most cases, though, the complexity of the machine or process necessitates a run-down period for “ramping down” production.

The setup period is the duration of time where the machine is stopped. In this phase, the equipment and process are being modified to manufacture new product. This time is critical, because absolutely no product is manufactured, and potential revenues are lost. Specific line components will undertake physical alterations, and software updates may be uploaded to automated equipment.

The run-up period is the duration of time after the setup period ends and full production is achieved. Full production begins when steady production at full capacity
occurs. During this time, tolerances, clearances, software parameters, etc. are adjusted such that the product is consistently acceptable.

Two key factors significantly attribute to downtime: (1) design, and (2) organization. If the work cell is of poor design, it will not easily facilitate exchange of die. Thus, focus can be put into modifying tool design to decrease downtime. On the other hand, organization plays another major role in downtime. Tasks can be allocated more efficiently so that the changeover time is reduced.

5.3.3 SMED Defined

In practice, SMED may be challenging to implement. In theory, though, SMED is simply defined in four steps:

1. Suppress useless operations,
2. Work together,
3. Simplify fittings and fasteners, and
4. Suppress adjustments and trials.

Note: These steps are non-sequential.

Steps 1 and 2 focus on organizational improvement; steps 3 and 4 focus on design improvement. These two concepts are described in detail in sections 5.3.4 and 5.3.5.

5.3.4 Organizational Improvement

Organizational improvement is concerned only with reallocating or modifying tasks—not equipment or product. In comparison to design improvement, organizational improvement is cheaper, easy to implement, and it produces very noticeable reductions in changeover time. For these reasons, lean improvement teams usually tackle organizational improvements first. There are several approaches to improving organization.

First, tasks can be re-allocated from internal time to external time. Internal time is the time during which the production line is stopped. Usually, the internal time and the setup time are the same thing, but it could be argued that run-up time is also included in internal time. External time, on the other hand, is defined as the time prior to the production line ceasing to manufacture. The idea is to move tasks from internal time to external time because fewer tasks within internal time will reduce the setup time.
(downtime). For example, a 15mm socket may be required to secure a new die in place during the setup phase. A particular task may be to retrieve the socket from the tool crib. This task, which may take a few minutes, can be performed in internal or external time. It would make sense perform this task in external time before the line is stopped. If the task is performed during changeover time, it only adds a few minutes to the changeover time. When the task is performed in internal time, the machine is out of production longer than it need be. By dissecting the changeover process, many tasks within a manufacturing process can be moved into external time, and the benefits can be quite noticeable.

Second, tasks can be reallocated so that they are conducted more in parallel. Of course, if tasks are to be performed in parallel, they must not be dependent upon each other. Usually, the creating of parallel tasks requires more manpower, so increased personnel must be considered.

Third, tasks can be more “compacted” together. Often during a changeover, there will be times when certain personal experience a “waiting” time between her or her tasks. A simple reallocation or reorganization of group tasks may help reduce this waiting time. Additionally, changeover procedures can be modified by broadening the scope of a technician’s abilities through training programs. This will allow a technician to perform tasks he or she was not previously allowed to do—and thus remove dependency on another technician for completion of a task.

The first three approaches only consider when the tasks should be performed. Of course, consideration for how the tasks should be performed is equally as important. For example, trials and controls can be minimized by formalizing procedures and utilizing standards. Checklists can be used, and technicians can be held accountable for key procedures by signing off on the checklists. But perhaps the biggest influence on how tasks are performed is to change the design of the equipment to better accommodate the changeover procedure. Section 5.3.5 explains in better detail.

5.3.5 Design Improvement

Another way to decrease setup time is through design improvement. Design improvement can be applied in one or both ways: (1) improve the design of the
manufacturing equipment, or (2) improve the design of the product of manufacture to accommodate the changeover process and reduce setup time. Design improvements can have a large impact on the efficiency of a changeover process. Unlike organizational changes, however, a large commitment company-wide may be required to conduct design improvements. Changing equipment design and/or product design can be very costly and time consuming. If increased productivity will eventually outweigh large investments, then design improvement is an avenue worth pursuing.

Equipment design improvements range from simple to complex. SMED heavily promotes the simplification of fittings on equipment. Or, if at all possible, fittings should be removed altogether. Consider a screw which holds a bracket on a piece of equipment. Only the last few screw threads actually secure the bracket, so there is no sense in having a screw with 20 threads. The added screw length only translates to an increased time to add or remove the bracket—especially if the bracket is held in place by ten screws. An even better alternative is to use clamps to hold the bracket in lieu of screws. As shown in Figure 6, clamps can be added or removed in one swift movement. The clamps and associated brackets may cost more than a handful of screws, but they will quickly pay for themselves in time savings.

![Figure 6. Use of Clamps](image)

Below are two more techniques for improving changeover efficiency:

- Items such as blocks, jigs, and templates can reduce the need for equipment adjustments, and custom tools can allow for quick changeover of components.
• Parts standardization for manufacturing equipment will increase changeover efficiency and reduce the quantity of required hand tools.

Finally, design improvement can also be applied to the product of manufacture. Not only should engineers design for functionality, but they should also consider the ease of manufacturing the product. If existing product does not accommodate the changeover process, effort could be put into modifying the product design. Again, this can be a large commitment from areas of business other than manufacturing. Of course, engineering effort is required, but sales, marketing, service, and procurement will also face the burden of product change. However, if the direction of a business is to have a dynamic product line, then the above departments should be geared for change anyway.

6 REFERENCES

