DEVELOPING AN INTEGRATED CURRICULUM FOR ERGONOMICS, PLANT LAYOUT, AND MATERIAL HANDLING LABORATORY EXPERIENCES

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Abstract - Ergonomics, plant layout, and material handling are very interrelated and interdependent disciplines. Unfortunately, these courses are often taught as separate subjects, with little overlapping commonalities. To maximize the learning process for students, however, it is important to establish the linkages between them, as these fields are so closely intertwined in actual industrial settings. Consequently, the objective of the initiative described here was to establish a series of laboratory experiences that would expose students to several of these issues simultaneously. Seven separate laboratory exercises were developed to accomplish this goal. These included handling granular materials, handling small packaged materials, handling bulk packaged materials, interfacing with mechanical handling systems, performing equipment maintenance, performing equipment and facility cleaning, and conducting a facility audit for ergonomics, plant layout, and material handling challenges and problems. These laboratory activities are subsequently being compiled into a workbook that can be used to supplement ergonomics, plant layout, and material handling courses. To augment these laboratory activities, however, the investigators plan to develop additional laboratory exercises in the future. This will allow instructors of each of these classes greater flexibility, because they will have the ability to selectively target specific laboratory activities to channel key information to the students. This ongoing initiative represents a key intersection between the disciplines of ergonomics, plant layout, and material handling, and will help fill the void that currently exists in these academic areas.

INTRODUCTION

Undergraduate engineering programs typically utilize capstone courses that allow students the opportunity to amalgamate and integrate their engineering knowledge and experiences, and solve complex, real world problems and hone their professional skills [2], [4], [7], [15]. Utilizing a materials handling and plant layout course is one practice that is commonly used to accomplish this aim and to meet these objectives. This type of design experience provides students the opportunity to combine disparate bodies of information, such as strength of materials, dynamics, mechanisms, fabrication processes, fluid mechanics, economics, and project management, to name but a few, by designing not only products, but the systems and processes which are used to produce them [10], [13].

The intelligent design and operation of manufacturing facilities encompasses not only efficient material handling processes, but also incorporates effective interfaces between humans and machines [8]. Work environments should be designed to accommodate human capabilities and limitations, to promote motion economy, and to minimize potential risks and hazards [11].

To date, however, there has been little development of applied exercises for use in ergonomics, plant layout, or material handling classes. Furthermore, no laboratory experiences that simultaneously address these disciplines have yet been developed. Consequently, the overall goal of this project was to initiate the development of several laboratory modules that would address this shortfall. Several of these exercises were gleaned from situations that commonly arise in the food and agricultural processing industries. (It should be noted that designers and managers of facilities that process food and agricultural products face ergonomic, plant layout, and material handling dilemmas similar to their counterparts in traditional manufacturing environments.) It is the intention of the authors, in developing these laboratory experiences, to provide students with hands-on applications of ergonomic, plant layout, and material handling issues, and to broaden their perspective by exposing them to this distinct, yet parallel, industry sector.

CURRICULUM STRUCTURE

The purpose of these laboratory exercises is to introduce students to the interacting and overlapping disciplines of ergonomics, plant layout, and material handling systems. Applying concepts in a laboratory setting has proven an effective route to learning, and thus has been the impetus for this curriculum development project. Students will have the opportunity for hands-on learning experiences and can synthesize information learned in the ergonomics, plant layout, or material handling classroom. To maximize the learning process, however, the seven laboratory experiences that have currently been developed all follow a standard methodology.

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Standard Laboratory Protocols

Prelab Questions

Prior to conducting any of the laboratory exercises, the students are required to reflect on the information they have garnered from the classroom and answer five standard questions.

1. What materials are commonly transferred via this operation?
2. What factors must be considered when designing this type of operation?
3. How does the trend in operating rate behave over time? Why?
4. What are some advantages of this operation?
5. What are some disadvantages of this operation?

Summary and Objectives

At the outset of each laboratory exercise, the students are given a brief overview of the goals for the assignment and the procedures to be used to accomplish those goals.

Background Information

Prior to completing each laboratory exercise, a brief review of applicable theory is presented. This should, in fact, be information that they have already been exposed to in the classroom setting, and the reiteration should thus reinforce the learning process for each student.

Materials and Methods

The requisite materials and experimental procedures vary between each laboratory exercise, and will be described in detail in subsequent sections of this paper.

Measurements and Calculations

Even though each experiment is unique in materials used and methods employed, the students are required to measure and quantify appropriate ergonomics, plant layout, and material handling characteristics for all the laboratory exercises. To accomplish this, students are required to answer five standard questions.

1. Determine the rate of material throughput.
2. Identify all ergonomic and material handling risk factors.
3. Identify all the repetitive motions involved in the system.
4. Quantify these repetitive motions.
5. If the laboratory is equipped with a biomechanics computer data acquisition program, connect the input sensors to the appropriate locations on a student's body. Repeat the experiment and use the computer software to analyze the biomechanics of the motions involved.

Additional Questions

To give the students the opportunity to integrate their experience in the laboratory with the information from the classroom, they are required to answer three additional standard questions after completing each laboratory exercise.

1. What could be done to improve the facility operations and/or material handling aspects of the system under consideration?
2. What could be done to improve the ergonomics of the system under consideration?
3. What could be done to improve the safety of the system under consideration?

Laboratory Report

After completing each laboratory exercise, the students are required to fully document their experiences and their findings in a formal report, following specific format and content guidelines prescribed by the laboratory instructor.

Handling Granular Materials

The first laboratory experience exposes students to the issues associated with manually handling granular materials (i.e., shoveling).

Although modern bulk material handling systems are widely used in the food and agricultural processing industries, shoveling still remains a vital element in many operations. Shoveling is especially important when cleaning material spills or when conveying equipment requires repair (i.e., has broken down) or requires maintenance, but the bulk material must still be transferred within a specific timeframe. Shoveling is typically a short-duration, high-intensity activity, and can produce muscle fatigue and even strain, both localized as well as whole-body. Many factors should be examined when considering the task of shoveling: type and size of shovel used, height where shovel must be used, height to which shovel must be raised, bulk density of the material to be transferred, weight of the material per shovel-load, total amount of material to be transferred, and timeframe for total material transfer [1]. Typically, as a person shovels, the ability to transport material declines with time (due to muscle stress and fatigue). Additionally, as lifting height increases, or as travel distance increases, load frequency decreases, due to increased time requirements for delivering each load.

Thus, the specific objectives of this laboratory exercise are to introduce students to both the material handling and ergonomic aspects of shoveling. To accomplish this, students are required to transfer 0.1 m^3 (26.4 gal) of a granular material from one location to another (which would preferably be a storage container) to simulate the process of cleaning a material spill, utilizing a repetitive, consistent methodology (Figure 1).

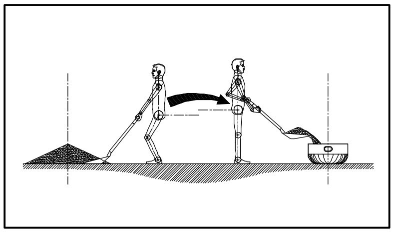

FIGURE 1
SHOVELING GRANULAR MATERIALS.

Handling Packaged Materials

This laboratory experience exposes students to the issues associated with manually handling and stacking small to medium-sized packages and boxes, which is a very common task in industrial settings.

Corrugated boxes and containers are very commonly used in the food processing industry to transport and distribute food products, especially to warehouse facilities and to end-use destinations such as grocery stores. These cases are typically durable, compact, efficient, shipping materials, and are either disposable or recyclable. Handling small boxes is typically non-taxing. As container size and weight increase, however, the stresses exerted on the body's muscles also increase. In order to ensure optimal material handling operations, maximum recommended box dimensions have been developed: 6 in high, 14 in wide, 20 in long [1]. Typically, as a person handles medium to large size boxes, though, the ability to transport material declines with time (due to muscle stress and fatigue). Additionally, as lifting height increases, or as travel distance increases, load frequency decreases, due to both increased stress and time requirements for delivering each box.

Thus, the specific objectives of this laboratory exercise are to introduce students to both the material handling and ergonomic aspects of moving relatively small packaged materials. To accomplish this, students are required to transfer 10 (at a minimum) small or medium-sized packages from one location to another (which could either be a storage shelf or another location in the facility), utilizing a repetitive, consistent methodology (Figure 2).

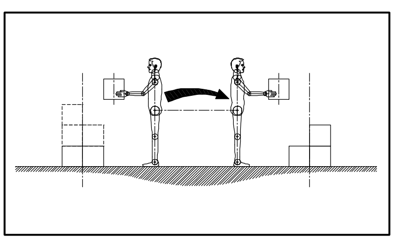

FIGURE 2
MOVING PACKAGED MATERIALS.

Handling Bulk Packaged Materials

This laboratory experience exposes students to the issues associated with manually handling and stacking large, 50-lb, bulk bags.

Bulk bags are essential to the food and agricultural processing industries. Many items, such as feed, meal, flour, seed, minerals, chemicals, and other dry powders are handled in this form. Advantages to using bulk bags include efficient transport by placing them flat on conveyors and pallets, and efficient emptying by opening the tops and pouring with a controlled rate of flow. Disadvantages of using bulk bags, however, include difficult lifting and handling, due to the heavy weights and the large sizes of these bags as well as the non-rigidity of these packages, and the susceptibility to damage because the walls of these bags are constructed of paper. Bags are typically transferred from horizontal position to horizontal position (e.g., simply transferred from one location to another), from a vertical position to a horizontal position (e.g., from a bag sewing operation to a storage location or a conveyor), or from a horizontal position to a vertical position (e.g., from storage to end use). Typically, as a person handles bulk bags, the ability to transport material declines with time (due to muscle stress and fatigue). Additionally, as lifting height increases, or as travel distance increases, load frequency decreases, due to increased stress and time requirements for delivering each bag. When designing bag handling operations, it is recommended that bag weights be kept at or below 50 lb, and that lifting of these bags be kept between 20 and 40 in [1].

Thus, the specific objectives of this laboratory exercise are to introduce students to both the material handling and ergonomic aspects of moving bulk packaged materials. To accomplish this, students are required to transfer five (at a minimum) bulk packages from one location to another (which could either be a storage shelf or another location in the facility), utilizing a repetitive, consistent methodology. This experiment can be conducted utilizing either a horizontal position for the bags (Figure 3), or a vertical position (Figure 4).

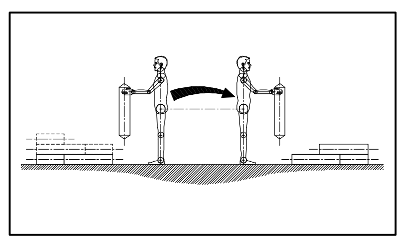

FIGURE 3
MOVING HORIZONTAL BULK BAGS.

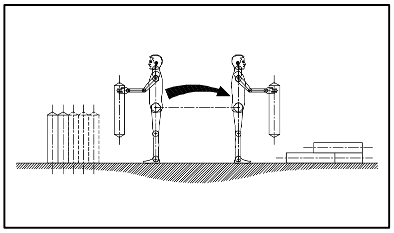

FIGURE 4
MOVING VERTICAL BULK BAGS.

Interfacing With Mechanical Handling Systems

This laboratory experience exposes students to the issues associated with manually handling small to medium-sized packages and boxes, and interfacing them with a mechanical handling system (i.e., a belt conveyor).

As mentioned previously, corrugated boxes and containers are very commonly used in the food processing industry. In processing facilities, these containers can be efficiently transported with either belt or roller conveyors. Typically these operations are fully automated. There are cases, however, when humans must interact with these process lines by either placing items onto, or removing them from, these conveyors [8]. When these cases arise, caution must be used to ensure that the conveyors are operated safely [14]. Handling small containers is typically non-taxing. As package size and weight increase, however, the stresses exerted on the body's muscles also increase. Usually, as a person handles medium to large size boxes, the ability to transport material declines with time (due to muscle stress and fatigue). Additionally, as lifting height increases, or as travel distance increases, load frequency decreases, due to increased time requirements for delivering each box [1].

Thus, the specific objectives of this laboratory exercise are to introduce students to both the material handling and ergonomic aspects of handling packaged materials vis-à-vis mechanical belt conveyors. To accomplish this, students are required to transfer 10 (at a minimum) small or medium-sized packages to, or from, an operating belt conveyor, utilizing a repetitive, consistent methodology (Figure 5).

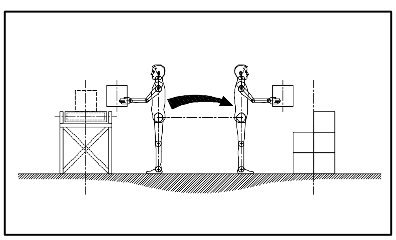

FIGURE 5
MOVING PACKAGES ONTO, OR REMOVING PACKAGES FROM, A BELT CONVEYOR.

Performing Equipment Maintenance

This laboratory experience exposes students to the issues associated with manually performing equipment and facility maintenance tasks, which are vital to ensure the optimum operation of all facility systems.

Maintenance tasks are typically performed on a specific time schedule (i.e., daily, weekly, monthly, or yearly). These activities include lubricating (i.e., greasing) bearings, changing filters, changing belts, adjusting equipment speeds and operations, and replacing worn parts, etc. Failure to conduct maintenance in a timely fashion could result in equipment failures, which, in the food processing industry, as in many other industries, results in lost production time, and thus, lost profits. While performing many of these tasks, workers typically utilize handgrip to accomplish their work (e.g., using wrenches or grease guns). Consequently the ability to grasp plays a key role in fulfilling maintenance duties [1].

Thus, the specific objectives of this laboratory exercise are to introduce students to the ergonomic aspects of performing equipment maintenance tasks. To accomplish this, students are required to loosen and tighten several bolts and nuts, and also to operate a grease gun to lubricate several bearings, utilizing a repetitive, consistent methodology for both tasks (Figures 6 and 7).

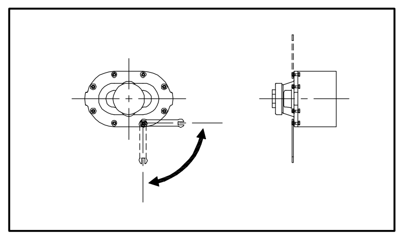

FIGURE 6
LOOSENING BOLTS AND NUTS TO DISASSEMBLE EQUIPMENT FOR MAINTENANCE.

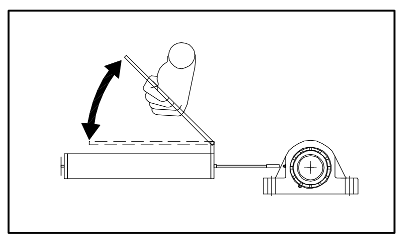

FIGURE 7
PERFORMING EQUIPMENT MAINTENANCE BY GREASING.

Performing Equipment Cleaning & Sanitation

This laboratory experience exposes students to the issues associated with manually performing equipment and facility cleaning and sanitation tasks.

In a food processing environment, routine cleaning and sanitation of all facility systems is vital in preventing microbial contamination of food products. Cleaning and sanitation tasks are typically performed on a specific time schedule (i.e., hourly, after each shift, daily, etc.). These activities include physically removing any remaining organic products, residues, or soils, by brushing, scrubbing, sweeping, or spraying (i.e., cleaning). After all facility and equipment surfaces have been cleaned, then they must be sanitized, in order to kill the microbial populations which may be living on these surfaces. Sanitation can be accomplished with steam or any number of food-grade chemical sanitizers. Failure to clean and sanitize in a timely fashion could result in microbial contamination in the food production line, which, in the food processing industry, results in lost production time or even product recalls, which subsequently results in lost profits or even bankruptcy. While performing many of these tasks, workers typically utilize handgrip to accomplish their work (e.g., holding a broom handle, brush handle, or spray nozzle), and thus the ability to grasp plays a key role in fulfilling cleaning and sanitation duties [1].

Thus, the specific objectives of this laboratory exercise are to introduce students to the ergonomic aspects of performing cleaning and sanitation tasks. To accomplish this, students are required to sweep, brush, and spray various surfaces, utilizing a repetitive, consistent methodology for these tasks (Figures 8, 9, and 10).

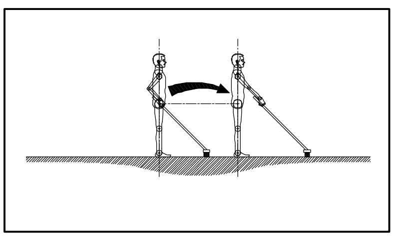

FIGURE 8
CLEANING FACILITY FLOORS BY SWEEPING.

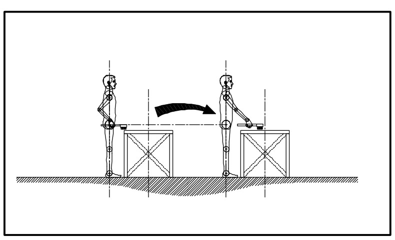

FIGURE 9
CLEANING EQUIPMENT SURFACES BY BRUSHING.

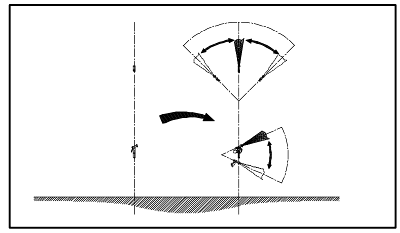

FIGURE 10
CLEANING AND SANITIZING EQUIPMENT AND FACILITY SURFACES BY SPRAYING.

Conducting A Facility Audit

The final laboratory experience exposes students to issues associated with investigating a facility for needed improvements to both material handling systems and to staff work environments.

Good engineering practice dictates that ergonomics concerns should be incorporated into the overall facility and system designs at the outset, before they are constructed, in order to increase productivity once the facility becomes operational and to simultaneously decrease potential problematic tasks [1], [8]. Unfortunately, these issues are not always addressed during either the planning or construction stages, and thus have to be remediated while the production facility operates, which typically incurs both economic and temporal costs [6].

Thus, the specific objectives of this laboratory exercise are to introduce students to techniques that they can use to critically examine facility layouts and work environments, and to allow students the opportunity to synthesize gathered information and provide suggestions for improving both the material handling and the ergonomic characteristics of the systems under consideration. To accomplish this, students are required to examine a facility environment (which could be a laboratory setup, a field trip to a production plant, a video recording of an actual operation, or a combination thereof), and consider all plant layout and material handling systems, all human interactions with machine systems, all ergonomics issues in the facility, and all safety issues in the facility. After completing the other laboratory exercises, and having covered many aspects of plant layout, material handling, and ergonomic issues, students should be well prepared to examine this production facility to determine if, identify where, and determine how to implement improvements that are crucial to system operation.

FURTHER NEEDS

This project represents an ongoing initiative to develop laboratory modules that will address the current shortfall of traditional ergonomics, plant layout, and material handling courses. Although several laboratory exercises have been fully developed, they have not yet been implemented in the classroom, and thus their effectiveness cannot yet be assessed. To be sure, upon implementation the exercises reported here will likely require adjustments and alterations, at least to some extent.

Furthermore, many more potential laboratory activities remain in a state of infancy. One category of experiments encompasses hand sorting and picking operations. These would include round objects, such as oranges, grapefruit, and apples, and irregular objects, such as corn, potatoes, and beans. A second category of experiments encompasses carrying buckets of various sizes via standard wire-based handles. A third category of experiments encompasses meat processing operations. These would specifically center around meat cutting procedures. A fourth category of experiments encompasses quality control tasks, including use of microscopes, balances, other bench top equipment, and small tools associated with these various pieces of equipment. A fifth category of experiments encompasses additional cleaning and sanitation functions (i.e., tasks in addition to those already described). A final category of experiments encompasses tasks associated with grocery stores, including stocking shelves with items of various sizes and weights, bagging groceries, and loading groceries into cars [3], [5], [9], [12].

Once finalized, these activities will solidify and deepen the curriculum which has been constructed thus far.

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REFERENCES

[1] Eastman Kodak Company. 1986. *Ergonomic Design for People at Work, Vol. 2*, ed. S. H. Rodgers. New York, NY: Van Nostrand Reinhold Company, Inc.

[2] Eder, W. E. 1997. Problem solving is necessary, but not sufficient. In *Proceedings of the 1997 ASEE Conference*. Available online: www.asee.org/conferences/97conf/00971.pdf [January 13, 2003].

[3] Hartford Loss Control Department. 2002. *Manual Materials Handling: Preventing Injuries in the Food Processing Industry*. TIPS S 190.020. Available online: http://www.thehartford.com/corporate/losscontrol/ [January 13, 2003].

[4] Hyman, B. 1998. *Fundamentals of Engineering Design*. Upper Saddle River, NJ: Prentice Hall.

[5] Janowitz, I., J. M. Meyers, J. Faucett, D. G. Tejeda, J. A. Miles, V. Duraj, and J. N. Kabashima. 1997. Reducing risk factors for the development of work-related musculoskeletal disorders in nursery work. Available online: http://ag-ergo.ucdavis.edu/papers/nurseryij.htm [January 13, 2003].

[6] LaDou, J. 1986. *Introduction to Occupational Health and Safety*. Chicago, IL: National Safety Council.

[7] Mendelson, M. and C. Caswell. 1997. Integrated product development in the classroom. In *Proceedings of the 1997 ASEE Conference*. Available online: www.asee.org/conferences/97conf/00860.pdf [January 13, 2003].

[8] Meyers, F. E. and M. P. Stephens. 2000. *Manufacturing Facilities Design and Material Handling*. Upper Saddle River, NJ: Prentice-Hall, Inc.

[9] Meyers, J. M., D. G. Tejeda, V. Duraj, J. Kabashima, I. Janowitz, J. A. Miles, and J. Faucett. 1997. Impact of selected engineering controls in reducing ergonomic risk factors associated with musculoskeletal disorders in nursery work. Available online: http://ag-ergo.ucdavis.edu/papers/impact.htm [January 13, 2003].

[10] Moore, J. M. 1962. Plant Layout and Design. New York, NY: MacMillan Publishing Co., Inc.

[11] Niebel, B. and A. Freivalds. 1999. Methods, Standards, and Work Design. Boston, MA: McGraw-Hill.

[12] Nowell, J. 2001. Testimony on Ergonomics Before Subcommittee on Labor, Health, and Human Services and Education of the Committee on Appropriations. Available online: http://www.senate.gov/~appropriations/labor/testimony/nowell.htm [January 13, 2003].

[13] Rossler, P. 1997. Toward complete, coherent production system design experiences. In *Proceedings of the 1997 ASEE Conference*. Available online: www.asee.org/conferences/97conf/01071.pdf [January 13, 2003].

[14] Schultz, G. A. 2000. *Conveyor Safety*. Des Plaines, IL: American Society of Safety Engineers.

[15] Voland, G. 1999. *Engineering by Design*. Reading, MA: Addison-Wesley.