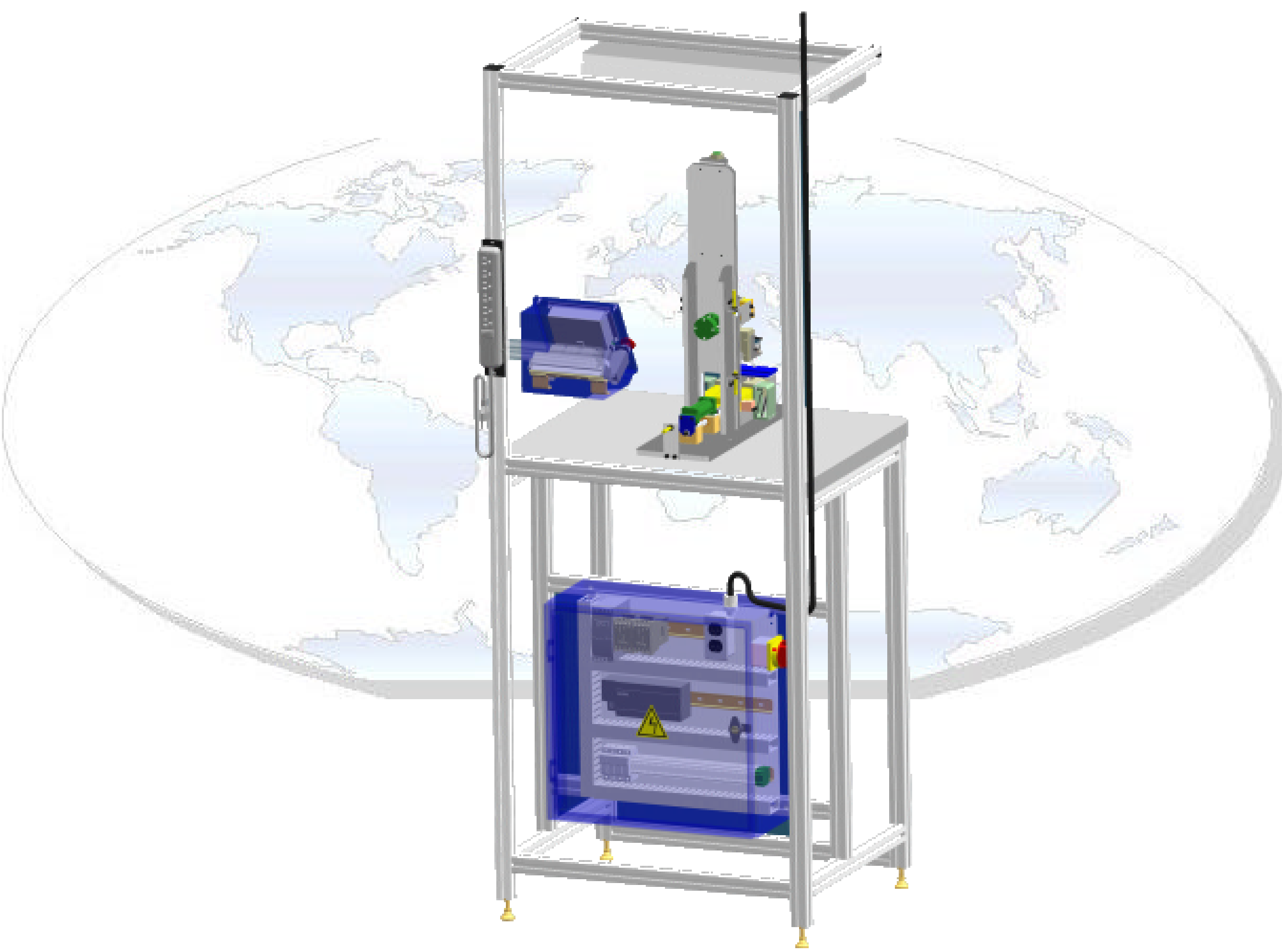
DELPHI

Automotive Systems

LEAN EQUIPMENT CONTROLS DESIGN



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First Edition Issued August 31, 2000

LEAN EQUIPMENT CONTROLS DESIGN

First Edition Issued (August 31, 2000)

Prepared by: **T&J TECHNOLOGIES**

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FORWARD

This manual supports the Lean Manufacturing initiative and is to be used by Delphi Manufacturing Engineers as a guideline for Manufacturing Equipment Controls Design. It was prepared in conjunction with the Manufacturing System Design (MSD) manual along with the *Lean Equipment Design* manual to provide additional equipment controls design characteristics that support the process goals of:

- ✓ Production-Focused Decisions
- ✓ Lean (Waste Eliminated)
- ✓ Flexible (Portable, Able to Run Every Part everyday)
- ✓ Customer Focused Modules/Cells at TAKT Time
- ✓ Run at TAKT Time
- ✓ One Piece/Small Lot Flow
- ✓ Value-Added-to-Value Added Operation
- ✓ People Engaged, Adding Value, Safely

The Manufacturing Engineering Task Team supports the Lean Manufacturing initiative because it results in reduced costs, increased customer satisfaction, and in our being a stronger company. We support this manual and we urge you to use it as a guide in performing this important work.

Delphi Automotive Manufacturing Engineering Task Team

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1 Introduction

1.1 Purpose

The purpose of this manual is similar to the *Lean Equipment Design*[1] manual: "guidelines for equipment design that will enable the implementation of the Delphi Manufacturing Systems (DMS)[2] and which are consistent with the principles outlined in the Manufacturing System Design (MSD)[3] manual."

However, the focus of this manual is on controls related issues, which provide further support and suggestions for creating lean equipment.

Therefore, this manual can be used for:

- Training equipment suppliers through workshops
- Exploring innovative solutions using current technology
- Concept and design of machines
- Evaluating design concepts relative to lean strategies

An effort has been made to maintain sections consistent to the *Lean Equipment Design* manual in order to promote cross-referencing of the content. Where covered adequately by that manual, particular sections are paraphrased or removed. Some new sections were added in order to satisfy controls issues.

1.1.1 Workshops

An effort should be made to educate equipment suppliers in lean manufacturing at Delphi Automotive. This manual is designed to be used in conjunction with meetings or workshops for this purpose.

Those attending these workshops should not only be controls engineers from Delphi and the OEM who concept and quote equipment, but must also be those of the controls community who will be involved in its design. Therefore, critical issues such as 'Design In Safety' can be addressed from the beginning.

For the workshops to be effective they must be conducted at the inception of a project.

1.1.2 Innovative Solutions

It is not the intent of this document to limit the exploration of innovative solutions to manufacturing challenges. The consideration of appropriate methods and devices, *which contribute* to *lean manufacturing* are encouraged. This may result in more than a new fix to an old problem. It may result in a paradigm shift.

1.1.3 Design Concepts

As options are being considered to solve the needs of manufacturing, this manual can be used to guide and direct the thinking of the design team. The examples given are provided to express lean ideas and are not intended to be the only solution.

1.1.4 Concept Evaluation

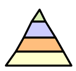
Once a manufacturing concept is solidified, this manual can be used to effectively appraise its validity relative to lean manufacturing ideas.

1.1.5 Definition of Symbols

Whenever you see this symbol, it indicates an idea starter to prompt further thought or consideration.

This symbol refers to shifts in philosophy or paradigm.

This symbol represents issues, which will benefit from the interaction of Delphi and OEM controls engineers with Manufacturing.

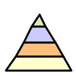


This symbol is used to indicate information or text which, to a large extent, was paraphrased from the *Lean Equipment Design* manual.

1.2 Review of System/Cell Design

The Delphi Manufacturing Engineering philosophy is to design manufacturing systems that achieve a balance between operators, equipment and materials. The goal is to provide the fastest response to the customer and build to customer demand, moving material in one piece or small lots from one value-added process to another without interruption and with the least amount of waste. Lean Manufacturing promotes product-focused plant layout rather than traditional process-focused layout.

Lean manufacturing requires that all people involved in the equipment design, specification, selection, and build have an understanding of the types of waste and work together toward their reduction.



Types of waste commonly found in manufacturing processes:

- Correction
- Overproduction
- Movement of Material
- Motion
- Waiting
- Inventory
- Processing

Some ways that waste can be reduced:

- Simplify
- Combine
- Eliminate

1.2.1 Process Requirements

There are seven Process Requirements for Manufacturing Systems. These are listed below:

1.	**Lean**	Eliminate all waste. Minimum amount of equipment, inventory, people, and lead time
2.	**Flexible**	Equipment configuration (portable)
		Ability to add or subtract people as volume changes, efficient for one operator to produce a product from start to finish
		Frequent changeovers, goal: run every part every day
3.	**Customer Focused Modules/Cells**	Capacity based on a single customer or small grouping of customers
4.	**Material Transfer**	One piece / Small lot
5.	**Material Flow**	Value added to value added operation
6.	**TAKT Time**	Available productive time / quantity required
7.	**People**	Engaged, adding value, safely

1.2.2 System/Cell Design Goals

Most of the equipment design goals are relative to the operator:

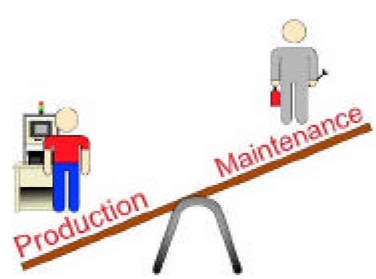
- Material handling strategies
- Arrangement, size, and shape of the equipment
- Minimizing wait time
- Safety
- Ergonomics

Additionally, there are other goals to achieve:

- Allow for continuous improvement
- Proper balance of manual versus automatic functions
- Maintenance
- Integration

1.2.3 Production-Focus

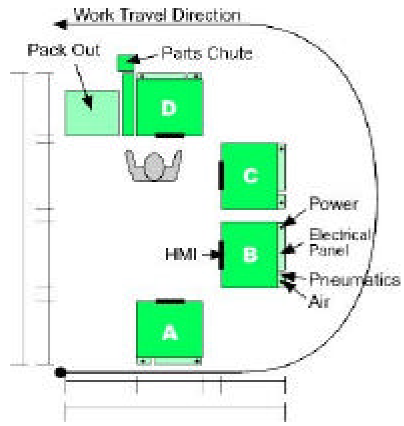
Controls engineering has long been a proponent of machine maintenance. It is important to note that lean thinking is heavily production-focused. Therefore, where compromises or conflicts between maintenance and production become an issue, support of production needs to be given priority.



1.3 Review of Manufacturing System Design (MSD) Methodology

The method for creating manufacturing system design is documented in the Manufacturing System Design (MSD) manual[3]. The MSD methodology is a team/workshop approach, which consists of the following steps:

- Determine Module Size
- Calculate TAKT Time
- Construct a Block Diagram
- Prepare a Machine Balance Chart
- Lay Out the System (including controls devices)
- Prepare an Operator Balance Chart
- Determine Buffer Sizes, Lot Sizes and Lead Time
- Determine Containerization and Packaging Requirements
- Error-Proof the System



Lay Out the System

TAKT Time/Module(sec/pc) **= Available Operating Time** (sec/day**) / Daily Volume Reqd** (pcs/day) **x #Modules**

1.4 System Simulation and Mockup

The simulation is a computer model which is used to analyze such things as system throughput, in-process buffer sizes, and number of resources.

The mockup is a physical 3-D model that allows people to touch it, try it out, and play "what if?". Mockups of machines should include:

- Operator panel(s)
- Control enclosure(s)
- Lockout location(s)
- Material rack(s)
- Cycle initiation device(s)
- Valve bank(s)

2 Equipment Design Guidelines

To support our manufacturing system design goals (identified in section 1.2) we must incorporate the following lean equipment design characteristics:

- Supports the Operator
- Simplified
- Supports One-piece/Small Lot Flow
- Portable and Flexible
- Zero-defect Quality
- Reliable and Maintainable

2.1 Supports the Operator

Operators should be doing value added work, not just watching equipment run. Keeping parts flowing smoothly with no interruptions is a sign of high efficiency. The lean control system in conjunction with the manufacturing equipment will help the operator achieve high efficiency by providing:

- Safe and effective guarding
- Immediate and useful feedback on the status of the system
- Immediate feedback on whether the work has been done correctly
- Physical space to perform the tasks

2.1.1 Safety and Ergonomics

In equipment design, health and safety are of primary concern. We must reduce and, if possible, eliminate ergonomic hazards in the workplace while maximizing operator productivity. Understanding human capabilities and limitations helps us to design equipment, tools and jobs that fit the wide variety of sizes, shapes, and capabilities of our workforce. Look to the Delphi *Ergonomics*[7] manual for further information.

2.1.1.1 Proper Lockout Placement

Equipment lockouts (electrical, pneumatic, and hydraulic) should be located in a central location in order to promote safety and serviceability. This is preferably at the rear of the machine.

Control specifications are now more open to different types of disconnect means, including attachment plugs for 120vac power. Rotary style disconnects also provide some possibilities. In any case, appropriate lockout must be available.

One central disconnect location for all utility lockouts is typically accomplished near the main electrical enclosure; however, cord and plug disconnecting means allow more flexibility in other locations as well.

In some cases, sub-buss systems and headers in the shape of the cell are the most cost-advantageous means to promote quick-change and relocation.

2.1.1.2 Simple But Effective Guarding

Proper use of guarding can make both the operator and the machine more efficient. Guarding must protect but not obstruct the operator. Further information concerning guarding can be found in the *Delphi Application Guideline for Safety Circuits*[10] and *Delphi Design In Health and Safety Specification*[11].

Some guarding options to consider:

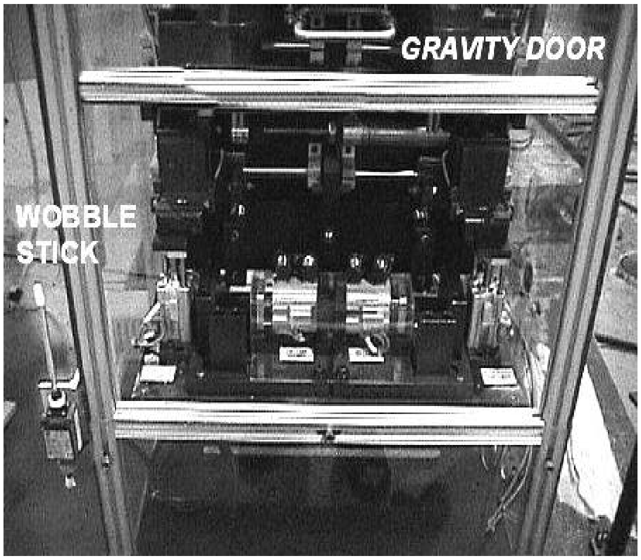
- Hard guarding
- Shuttle mechanisms
- Sliding barriers (see figures on next page)
- Bump strips
- Safety floor mats
- Light screens
- ‘Mix’ of above

Control engineers need to be involved in the selection of guarding options; both point-of-operation and perimeter guards, as part of the equipment concept(s).

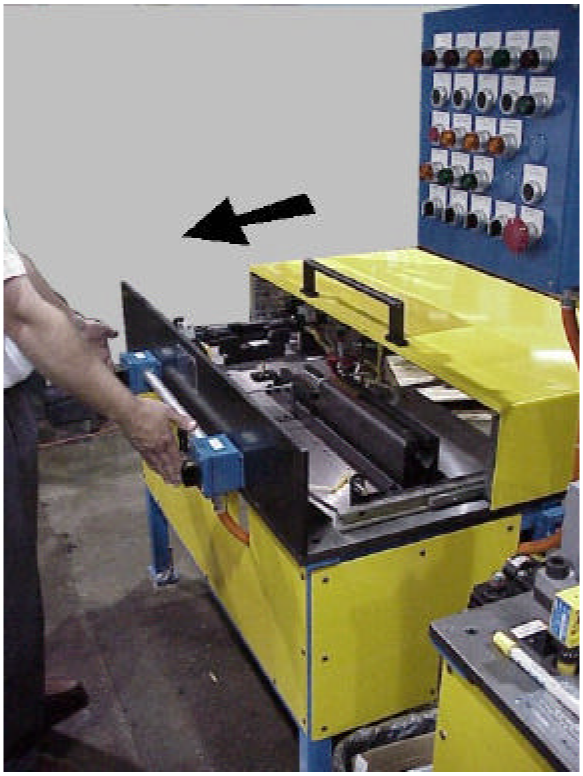
There are several points to consider in guarding discussions:

- ❑ Primary consideration should be given to eliminating the need for guarding by designing out the hazard.
- ❑ Simple mechanical guarding will result in (substantially) lower initial controls cost, complexity, as well as maintenance. (See “Guarding Cost Comparison Study May 28, 1998” following pages.)
- ❑ If done improperly, presence sensing guarding methods add control components, may disrupt walking patterns, cause extra reach distances, and do not protect from projectiles.
- ❑ Sliding barriers are very simple, but can increase operator time and ergonomic issues.
- ❑ Automatic shuttles may in themselves create additional hazards. The guard must not have dangerous pinch points.
- ❑ Risk assessment should take into account the possibility of a projectile.
- ❑ Light curtains can sometimes bring a false sense of security.
- ❑ Horizontally mounted light curtains should be protected from damage and contamination.

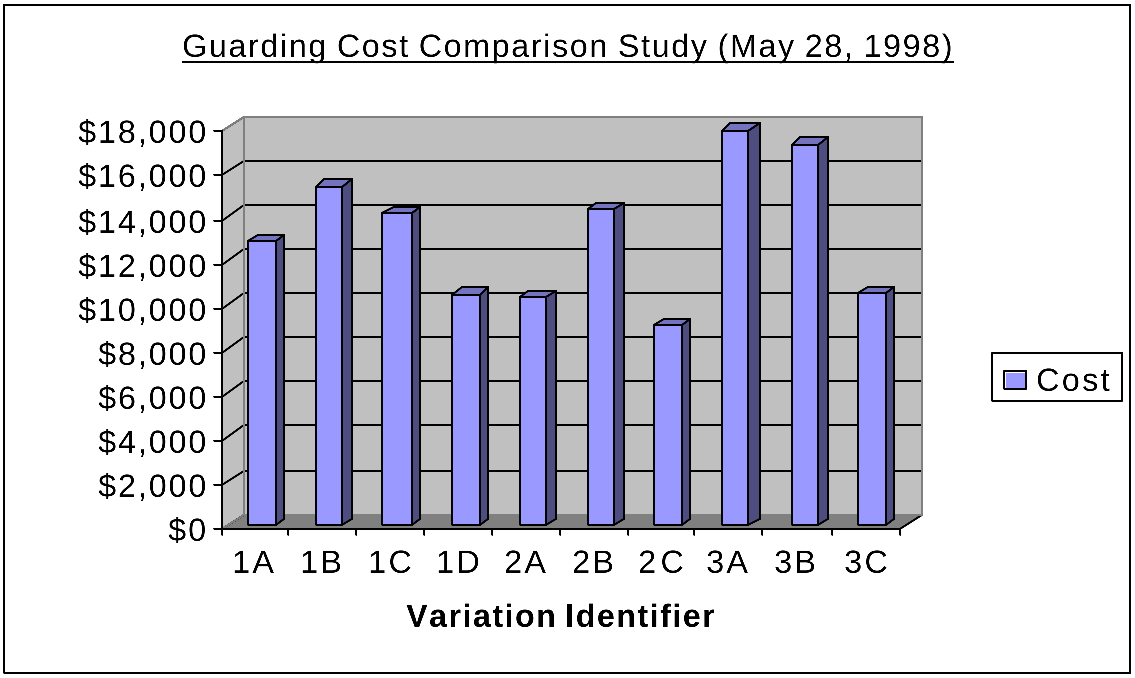
Equipment ***concept drawings*** should include guarding, wiring, fluid power, operator panel, control enclosure, and cycle initiation devices. Equipment concepts should not be approved without these features documented.



Gravity Door Does Not Harm Operator



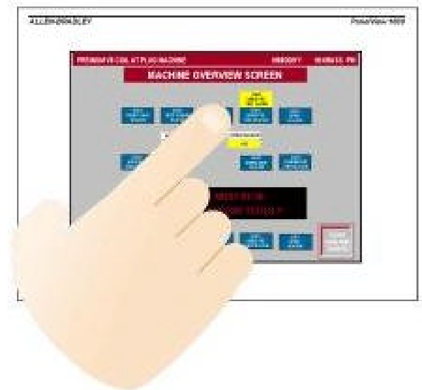
Guard Closes During Cycle



1	**Fully Enclosed Sheet Metal Guard -** Typical use is to protect the operator from chips, coolant, or welding.
A	Two-hand control with automatic sliding door.
B	Wobble stick for cycle start, an automatic sliding door, and a light curtain for operator safety.
C	Wobble stick for cycle start, an automatic sliding door, and a Safety Switching Rail (bump switch) for operator safety.
D	Manually close door for cycle start and it would automatically open at the end of the cycle.
2	**Open Front Expanded Metal Guard -** Typically used when protection from chips, coolant, or welding is not required. Operator protection is achieved with three expanded metal sides.
A	Wobble stick for cycle start and light curtain for operator safety.
B	Automatic part shuttle for load/unload of part. The shuttle encloses all pinch points and is designed with close tolerances so that no clamping of the part or shuttle is required. Safety is accomplished with a designed-in profile feature.
C	Manual parts shuttle with a shot pin to retain the shuttle and fixed guarding around the work area.
3	**Part Pass Through Open Front Expanded Metal Guard -** Similar to Machine 2 (above). Additionally, this type is used when parts are required to flow from one machine to another.
A	Wobble stick for cycle start and (3) light curtain beams in a "C-Frame" configuration for operator safety.
B	Wobble stick for cycle start and a Programmable Laser Scanner (PLS) for operator safety.
C	Wobble stick for cycle start and a 4' x 4' safety mat for operator safety.

2.1.1.3 Equipment Addresses All Ergonomic Issues

For detailed discussion of operator ergonomic issues, see *Ergonomics Guidelines*[7].



While smaller operator interface components (pushbuttons, LEDs, HMIs, gages, etc.) seem to support lean manufacturing, they can have a negative effect on operator ergonomics. (E.g. HMI screen pushbuttons that are too small for an operator's finger.)

We encourage the search of innovative "lean" components. However, their use may require more engineering for proper application.

Changes have been incorporated into the latest version(s) of Delphi control specifications such that machine controls construction can facilitate material handling around the machine. This can lead to improved operator ergonomics.

These are listed below:

- Enabled by the promotion of more flexible wiring practices, pushbutton boxes can be hinged or on slides (see figure below) to be easily moved out of production's way.
- Flexibility in placement of the main control enclosure location has been allowed through the reduction in terminal boxes, smaller enclosure size and internal mounting restrictions. (See Section 2.2.3 for more details.)

Pushbutton Box Slides In/Out

However, the proper application of other requirements can lead to inhibiting operator ergonomics:

- Distance formulas as required by national/international standards on the proper placement of presence sensing protective devices and other guarding methods.
- *NEC*[13] requirements for access to control enclosures (refer to section 2.1.8).

2.1.2 Select Proper Cycle Initiation

To make the operators more efficient they must be able to initiate the cycle, and move to the next operation with minimal or no wasted motion. Equipment can safely be started with a variety of devices, in many configurations, when done in conjunction with guarding (see section 2.1.1.2). Some of the devices used include: whisker switches, palm buttons, opto-touch switches, light curtains, and floor mats.

Some methods used for cycle initiation:

Two-hand Initiation

- **Two-hand initiation**: A configuration where an operator must use both hands to operate buttons or switches *for the entire hazardous portion of the machine cycle*. This method is cost effective and is recommended in cases where the cycle time is less than 3 seconds since the operator(s) will not be able to run multiple machines.

Wobble Stick

- **One-hand initiation**. When used in conjunction with active guarding (automatic barrier guarding, light curtain, or safety floor mat) the operator is able to press a button or switch while walking away from the machine. Wobble (or 'whisker') switches are often preferred because it is easy for the operators to position their hands without looking for the switch.

- **Presence Sensing Device Initiation (PSDI)**. This is a configuration that uses the light curtain to initiate the machine cycle. The operators simply remove their hands from the machine and the cycle is initiated. If a light curtain is used, then PSDI is a good way to initiate cycle. (Refer to the Application of Light Curtains[14], Section 7, which indicates appropriate implementation requirements.)

- **Slide or Door Initiation – Manual Open**. This configuration uses a switch in conjunction with the slide or door. The operators push the slide or close the door and the switch triggers the machine cycle. After the cycle is complete, the operators open the slide or door. The time required for the operators to perform the function should be considered in this method. Reliability of the switch should also be given attention.
- **Slide or Door Initiation – Automatic Open**. This is similar to the manual method but the slide or door is opened by the machine (shuttle) at the end of the cycle. Depending on the implementation, this method may be more costly yet frees the operators' time for other value added functions.

2.1.3 Reduce Machine Noise

In a lean system, operators need to hear and converse with each other and with maintenance and other support staff areas. Even though sound specifications determine maximum values, the lower levels can be achieved by means of appropriate design criteria:

- Mechanical considerations such as sound proof chutes, etc
- Air/Oil is less noisy than hydraulic.
- Use reduced noise compressed air nozzles.
- Properly designed hydraulic and air systems can be quiet.
- Conversely, poor fluid power designs are often noisy. Don't enclose the noise, design it out.
- Tie air system exhausts together. If the air is non-lubricated, this could be discharged to the hollow machine frame.
- Use of properly selected deceleration and speed control devices on cylinders will reduce 'banging'.
- Operator annunciation may add to the overall system noise level. Careful selection of the device (tones instead of buzzers) can be an advantage.
- Noise can be reduced by making the operator annunciation device physically directional. Only the operator needing the information can hear the sound.
- Provide volume control so the operator can set it to a minimum level. However, this adds to the cost of the equipment.

2.1.4 Simple Part Presentation Devices

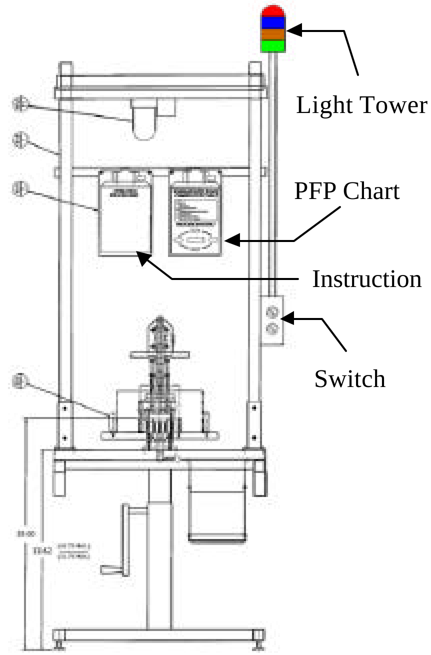
Part presentation devices should be reusable, re-configurable and/or flexible. Part presentation devices should be stand-alone so they can be moved to get access to the sides of machines. Part presentation devices should be designed to get parts to point of use from *behind the machine*, as well as get empty containers out of the cell.

Concerning priority, the *Lean Equipment Design* manual says, "Integration of part presentation devices with machine base and tooling should occur ***before*** (emphasis ours) guarding, piping, wiring, operator panel, and control enclosure location are finalized."

If error proofing in connection with part presentation is to be considered, see section 2.5.1.

2.1.5 Provide Necessary Visual or Audio Controls

To maximize the use of the operators' skills and attention, the operator must be kept informed. The equipment must have the necessary features to accomplish this.



Send output of machine to an Andon System. The key to an Andon system is to aid in communication with the operators and keep the line running. Operators use the system to call for help. Team Leaders, Maintenance, and Management use the system to support the operators. Refer to *Andon* Training[13] for further guidance.

Put cycle counters (fixed and reset-able) on machines to monitor tool changes and need for maintenance.

Use downtime clocks and TAKT Time clocks to provide instant information and help keep the pace.

Display fluid levels.

Limit the size of flowracks, or paint lines on them to indicate proper level of material and control overstocking or overproduction.

Use light towers on machines as another form of Andon (see figure). In this example, the operator is able to call for help with a switch.

Post simple straightforward graphic visual instructions in front of the operator at the workstation. Design a space to contain this information. Hint: Posting the PFP Chart reinforces the standardized work and supports continuous improvement.

Use a Human Machine Interface (HMI) panel to display important information. The HMI panel is typically a touch screen used for machine control, fault diagnostics and machine status.

The *Lean Equipment Design* manual presents some good information in regards to Andon boards and stack lights. Some additional controls considerations or clarification follow.

Control specifications no longer require as much spare space, spare I/O, etc. therefore ANDON requirements need to be **clearly** defined **prior** to machine purchase/build.

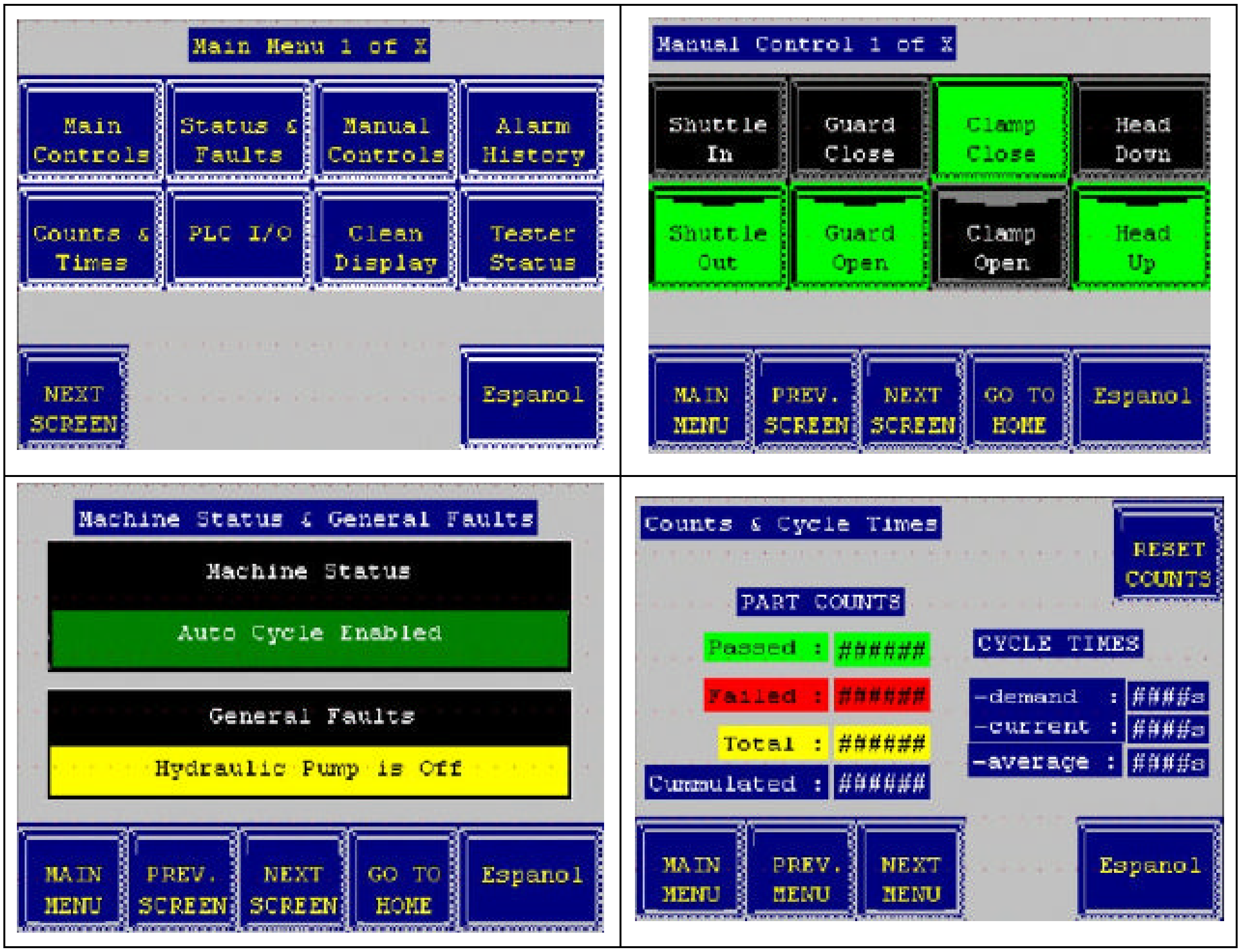
If applicable, the fluid level(s) should be displayed for the operator to view. This does not necessarily imply the control system should provide more than a high/low fault.

The decision to use Human Machine Interface (HMI) should take into consideration the requirements and needs of the particular machine.

- 'HMI' refers to a programmable display device, which replaces pushbuttons, lights, and message displays. The HMI may or may not be a 'touch screen'.
- HMIs can present much information in a small package, and are flexible.
- HMIs can be viewed as additional cost, particularly for simpler processes.
- Backup/restore of HMIs can add to long-term burden of in-plant controls.
- Issues that must be addressed include the readability of HMI from various angles, letter size, and screen fill percentage, and are discussed in *Ergonomics Guidelines*[7] Section 2.4.

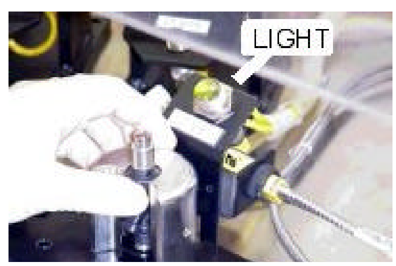
- Color HMIs have a significant cost impact compared to monochrome.

Sample HMI Screens Using PV600:



Audio annunciation can be valuable in improving the operator's efficiency by providing immediate feedback for such conditions as a cycle that failed to start, machine status, and part quality.

To provide immediate information in an ergonomically 'friendly' manner, Honeywell LEDs (in a proximity sensor body) are inexpensive and easily mounted right at the point-of-operation. The photo shown illustrates how an LED indicator is mounted in the operator's view to indicate part presence. (Reference Delphi Great Idea #009 for a single color indicator and Idea #059 for a tri-color indicator.)



LED Light

2.1.6 Workplace Organization

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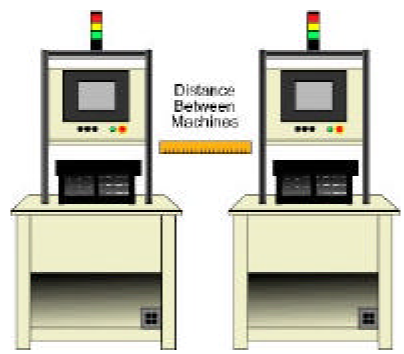
2.1.7 Pacing Mechanism

A pacing mechanism is required to let the operator know whether or not the rate of production is being maintained. Letting operators set the pace is the least favorable method of pacing, since they don't have an actual indication of how well they're doing and other cells may be held up waiting for parts. A better pacing method would be a display counter. This can be a real time display of parts produced vs. required. Another method is with a TAKT time countdown timer, allowing operator to pace their work throughout the cell. A method without a counter would be to automate the final machine in the cell, so it controls the pace. In all cases, it is important to tie the pacing mechanism to the Andon Board to allow real time monitoring of the system.

Pacing Mechanism

2.1.8 Distance between Machines

Distances between machines should be minimal. Walking from machine to machine is a non-value added function and can add up significantly during an 8-hour shift. Therefore, refer to section 2.2.3.7 for issues pertaining to electrical panel size and location options.



Note that *NEC*[13] Article 110-26 details requirements for working space access and clearance such that it…

> . . . be provided and maintained about all electric equipment to permit ready and safe operation and maintenance.
>
> . . . have 30-inch minimum access or clearance.
>
> . . . allow 6-½ foot headroom.
>
> . . . is 3 to 4 feet deep, dependent on voltages and grounding present.
>
> . . . maintain 90° door swing. Delphi controls specifications expand this requirement to 120°, partially to take into account control devices typically mounted on the door and the width and depth requirements mentioned above.
>
> . . . shall *not* be used for storage.

Complex machines with high maintenance requirements may need to have increased access.

2.2 Simplified

More and smaller modules lead to greater TAKT time and the opportunity to slow machines down. Simplified equipment reduces both investment and downtime.

We need to start with an understanding of how to build 'just one'. As we speed things up and add automation to the basic process, we add complexity. Putting the complexity into the tooling, rather than the machine, can reduce cost and improve flexibility (e.g. drill, chamfer, and counter-bore on one tool instead of three (3) separate machines). When automation is required, don't use excessive electronic controls when simple mechanical devices will suffice.

2.2.1 Proper Use of Automation

Understand what needs to be controlled and how best to use people for value added tasks and *automate only* where *necessary*. To be "less automated" means to focus on automating the right things. Minimizing the use of automation reduces capital. An example is using adjustable stops on a cylinder instead of a servo system. The cylinder is a more robust solution because of the following:

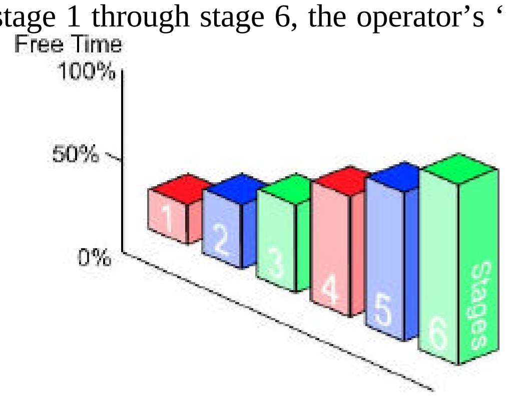
- Less downtime
- Simpler maintenance
- Longer life components
- Servo system component obsolescence

2.2.1.1 Levels of Automation

According to the book *A Study of the Toyota Production System*[4], there are various stages in automating equipment. These are briefly related here:

1. Manual: Manual load, manual process and manual unload.
2. Manual: Manual load, automatic process (operator waits) and manual unload.
3. Manual: Manual load, automatic process (operator does other things) and manual unload.
4. Semi-automatic: manual load, automatic process and automatic unload.
5. Pre-Automation: load, process, and unload. Equipment maintained by operator.
6. Automation. Includes entire automatic processing, trouble detection, and correction.

As we progress from stage 1 through stage 6, the operator's 'free' time increases from 0% to 100%. However, the cost of the equipment from stage 1 through stage 6 dramatically increases. Therefore, when justifying the cost of increased automation, we need to look at what we are *really* saving by doing so. For example, local labor rates and characteristics of the work force should be considered.



It is our observation that a "lean" machine typically fits from stage 1 through 3. A lean machine can also fit stage 4 if the unload mechanism is simple.

2.2.1.2 Manual Loading

While manual loading has its advantages (operator performs part orientation), ergonomic guidelines establish restrictions that must be carefully examined in the design process. For more information, refer to *Ergonomics Guidelines*[7] Section 3.

Task Light and Personal Fan

High operator attention areas will require task lighting that moves with the machine. This adds to the purchase price, and needs to be considered prior to machine purchase/build for inclusion in controls specification / panel space.

2.2.1.3 Manual Unload vs. Auto-Eject

"Auto-Eject" is a feature incorporated in the machine which either simply dislodges a completed part from the nest for easier operator retrieval or it completely removes the part from the machine. In any case it should be a simple device.

Always consider the elimination of pinch points in even simple mechanisms.

2.2.2 Use "Off-the-Shelf" Machines

"Off-the-Shelf" machines must meet applicable standards relative to the type of equipment being supplied as well as take into consideration the destination location. For example, the requirements for electronics manufacturing equipment may differ from that of typical industrial equipment (i.e., NFPA 79[5], Delphi *Addendum*[6], and ANSI).

When considering the application of "off-the-shelf" equipment, one must weigh the entire life cycle of the process and not just initial cost of the equipment.

Are there "proprietary" components (e.g. controls, tooling, etc) on an off-the-shelf system that limit long term flexibility and support?

Given the above constraints, primary emphasis should be placed on working with purchasing and machine suppliers to make the Delphi machine a 'shelf' item. The "Delphi machine" is one, which can apply throughout the Delphi organization in lieu of a single plant.

An interesting compromise between custom and shelf machines is the application of reusable engineering and/or designs. By starting with a library of existing designs, which have been proven in the past, design time can be greatly reduced. This library can be enhanced through continuous improvement. This will result in improved delivery and cost of equipment.

2.2.3 "Right Sized" Electrical/Mechanical Components

Design to meet the requirements (no-overkill). Don't pay extra for what is not necessary. It drives equipment size larger and cost higher.

Controls must be designed to match the process. The process must be made lean first then controls can match.

Control specifications have been changed over the past few versions to enable and encourage the application (but not limited to) the following:

- Use 120vac service power
- 24vdc control system
- Low end controllers
- Networked/block I/O
- Use I/O module as termination
- Use IEC components
- Design for 10% spare enclosure space
- Use position sensors only as necessary
- Consider higher hydraulic pressure to reduce size of mechanical devices
- Use manual tools (arbor press) instead of powered tools
- Size motors appropriately (use 2 hp instead of 5 hp if that is all that is needed)

2.2.3.1 120vac Service Power

Items to consider when evaluating the use of 120vac as the machine power source:

- May decrease size of the main enclosure.
- May eliminate the need for a transformer at the machine.
- Typical or standard 120vac outlets are designed to supply 20amp maximum.
- Elimination of on-the-door/enclosure disconnect (through use of plug).
- Current specification does not require panel door interlocking for 120 volt supplied systems. (Delphi *Addendum*[6], *Section 7.9.5*.)
- Requires facilities to look at 120vac-distribution system(s). (See Section 2.4.5).
- If the only requirement for 480vac is a hydraulic power unit, *consider* using a separate supply and disconnect (figure at right), thus retaining the enclosure size advantages associated with 120vac-service power.

2.2.3.2 24vdc Control System

There are advantages and disadvantages to weigh when considering the use of 24vdc for the control system as well as the I/O circuits.

Advantages:

+ 24vdc components are generally smaller than 120VAC counterparts.
+ Less electrical shock hazard than 120VAC circuits.
+ Consistent coil response.
+ No frequency problems.
+ Some devices are only available in 24vdc configurations.

Disadvantages:

- Additional component(s) (e.g., power supply) mounted on the subplate.

- ‘Switching’ power supplies can cause noise. Yet, ‘linear’ supplies are larger.
- 24vdc indicators can be difficult to see. While ‘LED bulbs’ are brighter and last longer, they are expensive.
- There can be confusion about grounding, labeling, and pnp versus npn devices.

2.2.3.3 ”Right-sized” Controllers

First determine the machine requirements and then match a controller to the requirements. Some issues to consider are:

- Memory capacity
- I/O type and count
- HMI and other communications
- Networking
- Preferences of the end-user destination

Low-end controllers can provide both cost and space advantages. Most of today’s controllers provide these advantages without compromising functionality.

2.2.3.4 Networked/Block I/O Modules

Where a significant number of conductors will have to be routed over a machine and/or through a junction box to be connected to the controller’s I/O, consider networked I/O modules. While mounting an I/O module remotely may add a small enclosure, the benefit is the reduced number of wires and cables.

Wire management systems are available in which (short) standard sensor cables (mini/micro) connect to a collection point of up to (8) devices. From this point a single multi-conductor cable is routed to the enclosure, thus reducing the total number and the length of sensor cables.

2.2.3.5 Using I/O Modules as Termination

Note that terminals of I/O modules can be considered a “terminal point” which should reduce enclosure size through eliminating hardware. However, high-density modules (e.g. more than 16 points) can be difficult to wire and maintain due to the close proximity of the terminals. Additionally, since larger more durable wires are required outside the enclosure, space allocated for wires can become a constraint.

Test point terminals could be located away from the rest of the terminals or I/O boards for ease of maintenance reach. (Delphi *Addendum*[6], subclause 16.2.3)

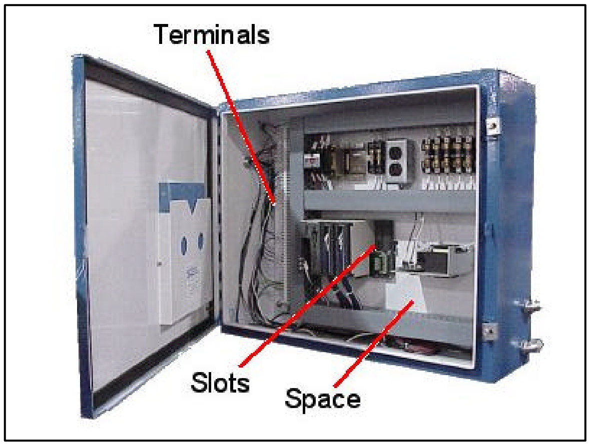
2.2.3.6 Using IEC Components

Components manufactured to IEC standards are often the smallest available. When properly used, IEC components can reduce the electrical enclosure size. However, there may be additional engineering when sizing and specifying IEC components such as motor starters, pushbuttons, etc.

2.2.3.7 Spare Control Enclosure Space

Minimizing the overall enclosure size can also be accomplished by reducing the space reserved for the possibility of additional components. Note that while Delphi *Addendum*[6] subclause 12.2.13 requires a minimum of 10% spare space, the italicized words discuss waiving this requirement. When designing an enclosure and its associated subplate, take the following into consideration:

- The realistic "need" for spare space.
- **Clearly** defined process.
- Can the process be downsized in order to reduce the enclosure?
- Continuous improvement of the process.
- The addition of error proofing during development.
- Current and future Andon requirements.
- Reducing the quantity of components through combining and elimination (e.g., grouping of motors).
- Options for future expansion (i.e. additional enclosure).
- Consider if 'spare space' can be found in: (See next figure.)
    - Termination
    - Controller slots
    - Empty mounting devices (e.g. fuse blocks).



Minimize Spare Space

2.2.3.8 Position Sensors

Limit position sensors to only what is needed. Some devices do not require a position sensor on each end of travel. The auto-eject (section 2.2.1.3) is an example of an application that doesn't need a sensor because if a motion does not occur the operator can observe it.

2.2.3.9 Pneumatic vs. Hydraulic

The most important factor in determining system type is comparing initial material costs with long term operational (maintenance & utilities) costs. Because of the variables such as actuator speed, force, and cycle rate each application must be evaluated individually.

- Force requirements and pressure availability determine actuator size restrictions. Delphi current specifications limit the maximum operating pressures for pneumatics to 70 psi (Delphi *Pneumatic Addendum*[10] *subclause 4.4*) and hydraulics at 3000 psi (Delphi *Hydraulic Addendum*[9] *subclause 4.4.1*). Higher pressures allow the use of smaller actuators, which in turn reduces the overall size of the equipment. However from a floor space requirement, this equipment size reduction is offset because of the addition of the hydraulic power unit.

- ❑ Operations with single actuators with force requirements less than 2000 lbs. should consider pneumatics because of lower initial cost.
- ❑ Operations requiring multiple actuators with low force requirements (<500 lbs.) should use pneumatics.
- ❑ Operations requiring multiple actuators with high force requirements (>500 lbs.) should consider hydraulics because of comparable initial equipment costs but with reduced long term operational costs.
- ❑ Consider the impact of hydraulic and lubricated air system leaks to the process and area. Leaks may be transferred to the product affecting part quality /customer satisfaction. Proper fittings shall be used to increase system cleanliness and reduce operational costs. (Reference ISO-4413, ISO-4414, and Delphi *Pneumatic*[10] and *Hydraulic*[9] Addendums.)
- ❑ Applications requiring critical velocity, acceleration, deceleration or positioning control shall require hydraulics.
- ❑ Properly designed and applied air/oil systems shall be considered for high force applications.
- ❑ Sound reduction techniques must be applied to all systems to stay within recommended OSHA/DA-SL1 requirements.

Additional items to consider in determining the system type are:

- Pneumatics involves trapped (compressed) media, which can be a safety hazard adding to the complexity of lockout/energy control. Note: This situation can also occur on hydraulic systems incorporating an accumulator.
- Non-lubricated (dry air) systems shall be used. Delphi Automotive approved components lists should only include actuators intended for dry service. This reduces initial equipment and long term operational costs. Where absolutely necessary, single point lubrication shall be used (reference Delphi-A fluid power example circuits).
- Both pneumatics and hydraulics require additional utility connection(s). Hydraulics may also require water connections for cooling, and adds related costs such as:
    - ? Increased panel size to house motor contactor/fusing.
    - ? Increased conduit size and wiring.
    - ? Addition of motor start/stop pushbuttons.
    - ? Requires 480vac supply with related components.

2.2.4 Minimize Use of Conveyance

The first choice for moving parts between operations within a cell is manually by the operator. Heavy parts that require operator assistance may require a conveyor or other operator assist equipment.

When modular powered conveyors are used, the controls should also be stand-alone for portability.

When variable speed is required, consider whether an electrical or a mechanical solution is the leanest.

If variable speed is accomplished electrically, design for minimal requirements. Direct current motors works well for relatively low torque and power applications. Recent cost and size trends in variable frequency drive hardware are making them a more attractive solution.

Proper use of gravity can be advantageous, but gravity can also be the source of a hazard.

2.2.5 Eliminating Waste in Equipment

2.2.5.1 Combining operations

In order to eliminate waste in a system, designers will consider not only the operator balance chart, they will also study a machine balance chart. The *Lean Equipment Design* guideline highlights an example machine balance chart in Section 2.2.5.

When non-value-added steps, machine wait time, and/or operator wait times are reduced, the result is a leaner system. Eliminating or combining operations can often accomplish this. However, care must be taken that added complexity in the required controls circuits do not offset the simplification gained by complex operations.

For example, the *Lean Equipment Design guideline discusses combining operations as a method of eliminating waste. In reference to the example cited, combining the noted operations puts the spin weld in close proximity to the operator. To obtain practical safe distance from a rotating spindle depends on some complex safety circuit to manage braking and removing power from the drive controller during load / unload. Their bullet says "eliminating and combining" reduced machine cost and complexity - but proper safety design will have added to control cost and complexity.* ***In all cases the complete life cycle costs have to be considered.***

2.2.5.2 Point-of-operation loading

Loading at the point of operation must be considered if it can be done safely. Further considerations include:

- Designing ‘out’ the hazard for loading to point-of-operation minimizes control safety circuit complexity, which should increase machine uptime and decrease machine purchase cost.
- If it is impractical to design out the hazards, adding a transfer mechanism to isolate the operator from the hazards may be a less costly overall solution than using complex safety devices and circuits.

2.2.5.3 Separating operator from hazard

The *Lean* Equipment *Design* guideline suggests that small 2-position dials can separate the operator from hazard areas. It should be noted that with a dial, or any part transfer mechanism, ***the transfer itself*** could be a hazard. A risk assessment process needs to evaluate the severity / potential of the hazard, and whether the risk can be lowered to one where monitored redundant circuits ***are not required***.

2.2.5.4 Cycle time vs. TAKT time

In reviewing the system/cell design it is suggested to compare the cell TAKT time to machine cycle time(s). Control designs need to consider the positive or negative affect on cycle time contributed by:

- the control system reaction time
- cycle initiation technique
- guarding methods
- pneumatic vs. hydraulic vs. electric

Keep in mind that reaction time of the control system is a function of the velocity of the devices. If shortened cycle time is to be achieved by increasing the speed of a motion (e.g. opening a flow control), the safety of the machine must be re-evaluated.

Cycle time is often considerably less than TAKT time leaving opportunities for the best life-cycle cost and safe machine guarding options.

Example: When cycle time is short enough in comparison to the TAKT time, then a simpler and less expensive *mechanical means (e.g. sliding guard door which adds cycle time but remains less than TAKT Time) should be implemented in place of a light curtain. With no adverse effect on cell TAKT time this could:*

- *improve operator safety*
- *lower costs*
- *improve system uptime (relative to controls)*
- *improve machine maintainability (relative to controls)*

2.2.6 Minimize Machined Surfaces

The *Lean Equipment Design* guideline asks ‘why pay extra for machined surfaces which are not needed?’ Note that if non-conductive material is used to eliminate machined surfaces, proper machine grounding needs to still be accomplished.

2.2.7 Simplify Gaging

Keep gaging simple and flexible (e.g. surface plates, dial indicators, etc.). Try to incorporate gaging into the downstream operation fixturing.

2.3 Supports One-Piece Flow

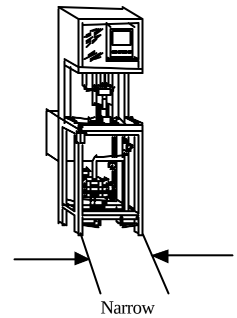
The benefits of one-piece small lot flow are:

- Faster lead time (customer responsive)
- Lower inventory (improves cash flow)
- Higher quality (quicker error detection)
- Shorter operator walking distances
- Easier visual management

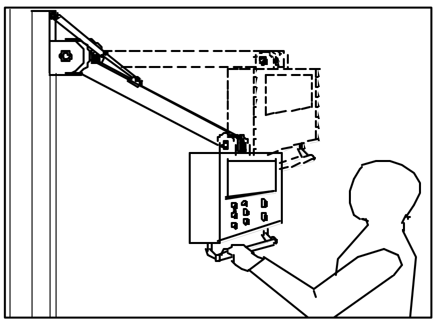
To support one-piece flow, machines must be close together so that operator walk distances are minimized. If walk distances are large, operators will be tempted to batch parts and store extra inventory between machines.

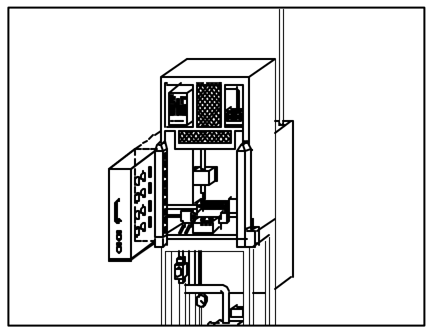
2.3.1 Narrow Effective Width Machines

The machine should be kept to a width slightly larger than the width of the smallest part dimension. This reduces walking distances and material movement as well as allowing material to be moved to the point of use from behind the machine. Keeping the control enclosure low at the rear helps keep the center of gravity low, which helps in machine relocation and allows space to move parts into the work area from behind the machine.



Pull down (below left) or slide out (below right) operator panels can reduce effective machine width.





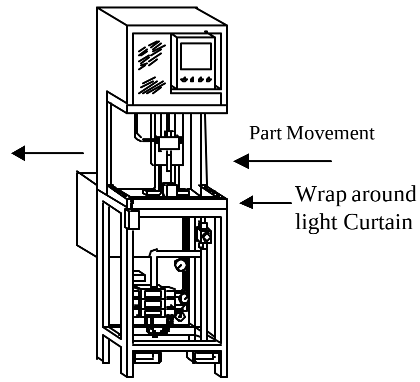
While striving to minimize machine width, it is important to keep the following in mind:

- Operator panels should not interfere with or be behind a machine guard or light curtain.
- All control component adjustments (sensors, pressure control, speed, etc) must be able to be made ***safely*** from the front or back of the machine. Thus it may be a good idea to define and detail the components needing frequent adjustment prior to machine purchase/build.
- Carry out wiring practices which reliably support the flexibility required for the situation.
- All applicable codes and specifications for enclosures and subplate design as well as working space requirements must be followed.

Since lean thinking is heavily production-focused, where compromises or conflicts between maintenance and production become an issue, support of production must receive priority. However, some maintainability issues should be kept in focus:

- Normal machine troubleshooting requires cycling the machine with the panel open. Therefore, the machine must be capable of running with the material handling "rolled" out of the way
- When considering swing-out or movable control enclosures, try to avoid hampering maintenance.
- Service areas should be at the back or front of the machine with no side access required. Side access requirements force machines further apart increasing effective width.

2.3.2 Machine is Open on the Sides

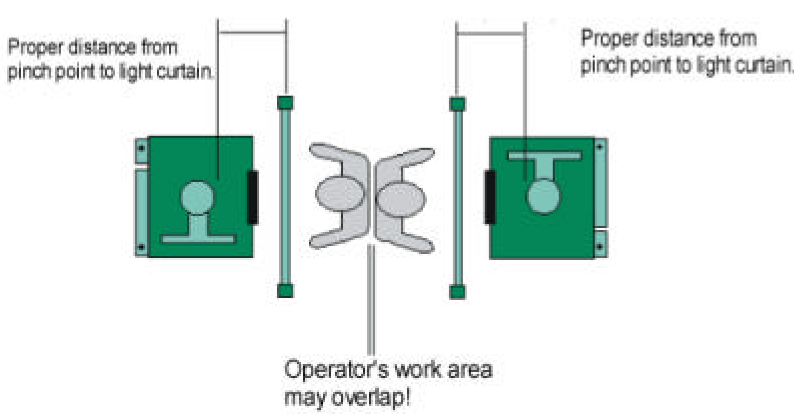


The use of C-Frames eliminates wasted motion of moving parts around posts and reduces possible part damage due to added part handling.

Controls Engineering needs to be involved in the overall machine design in order to incorporate controls lean concepts.

When designing machines with open sides there are several guarding considerations to take into account.

- As a reminder it is always better to eliminate the hazard thus reducing or eliminating the guard requirements. Guarding should be treated as a 'last resort' solution.
- Keep it simple while adhering to the law on guarding distance from hazards.
- Controls specifications and guidelines identify required safe distance formula.
- When light curtains are used, the following considerations apply: A combination of hard guard and light curtain may be optimal for spacing yet this method may require a higher purchase price.
- Due to space limitations, wraparound or multiple light curtains (see figure above) can be controlled using one controller. However, multiple light curtains add control complexity and cost.
- Not all light curtain manufacturers have products capable of these configurations.
- Use of multiple light curtains requires additional components to be mounted on the machine.
- Longer light curtains or multiple light curtains have a slower reaction time.
- Light curtains in the horizontal plane require additional protection from contaminants and damage and they require precise mounting to eliminate dead spots at the corners
- Proper mounting (i.e. distance from hazard) of any safeguard device needs to be taken into account and may increase the space between machines (see figure).



2.3.3 Avoid Large Batch Type Off-Line Equipment

Utilizing multiple smaller machines in lieu of large batch processing equipment within a cell has the following advantages:

- Reduces inventory.
- Decreases operator travel distances.
- Facilitates one-piece/smaller lot flow.
- Allows more flexibility.
- Makes change over and relocation easier.

It should be noted that batch processing had allowed component ***commonization by area and departments***, whereas intermixing different processing equipment into cells should put more of an emphasis on ***commonizing components across an entire division/site***.

However, an issue that could be considered a disadvantage is the perceived increased cost due to multiple control panels, controllers, HMIs, and other hardware such as safety and error proofing equipment.

2.3.4 Review Multiple Operation Equipment

(Left blank intentionally.)

2.3.5 Manual Backup

(Left blank intentionally.)

2.4 Portable and Flexible

Equipment must be as portable and flexible as possible. A goal in flexibility is to be able to react to changes in volume, product design or delivery timing. Remember we want the ability to run "every part every day" if the customer requires it. Portable equipment makes relocation possible with minimum cost, allowing for continuous improvement in manufacturing system design. The goal of machine relocation is: good part to good part in 4 hours or less. These efforts will also make installation and qualification easier.

2.4.1 Design Equipment to be Self Contained

Self-contained equipment is easier to move because no rewiring or piping is required. Consider keeping the following all on one base:

- ❑ Control enclosures
- ❑ Operator panels
- ❑ Hydraulics
- ❑ Cooling Systems
- ❑ Chip Collection
- ❑ Leveling
- ❑ Vibration Isolation

Alternatively, the equipment can be designed for relative ease of relocation by utilizing special shipping configurations along with 'quick' connections.

Hydraulic Power Unit

Hydraulic power units do not always need to be an integral part of the machine. Consideration could be given to a remote location because of:

- "house keeping" type issues
- quick change processes which can share hydraulics power supply
- sound levels

2.4.2 Provide for Flat floor Mounting

(Left blank intentionally.)

2.4.3 Avoid Fastening to Floors

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2.4.4 Use of Fork Pockets and Casters

Design equipment with fork pockets or casters for ease of relocation. When using casters, use lockable wheels to keep machine in position. These should be considered during cell mock-ups as well as mounting locations for control devices.

2.4.5 Use Flexible Drops and Quick Disconnect Utility and Ventilation Connections

The goal of machine relocation is: good part to good part in 4 hours or less. Therefore, keeping utilities and ventilation above ground using flexible drops and quick disconnects is promoted. Avoid steam and natural gas. Flexible electrical connections will be done only as allowed by the *NEC*[13] *(Ref 364-8).*

- Strain relief devices should be used to tie hoses and cables to machine to prevent accidental strain on them.
- Enough extra line for slight movement of equipment without disconnecting shall be provided. (Note: *NEC*[13] requires vertical flexible drops.)
- Although 120vac power has been allowed for some time, allowance of plugs as the disconnecting means promotes the use of 120vac power. (Delphi *Addendum*[6], subclause 7.11.)
- Consideration must be given to plant utilities for cells, which will be predominantly 120vac/20a powered. (See subclause 2.2.3.1 above.)
- Refer to Delphi Automotive documented flexible drop recommendations. (See Delphi Automotive Best Practice #CEBP9801 for details.)
- For applications using 480vac, electrical flex drops are not economical for supplies over 60amps.
- Before choosing the utility connection means, an evaluation of the most probable scenario should take place:

  ⇒ Will the entire cell be relocated?, or…

    ⇒ Will equipment within a cell be rearranged or oriented differently?, or…

      ⇒ Will machines within a cell be moved and swapped?

2.4.6 Support Quick Changeover

The cell or process must have the ability to run every part every day and quick changeovers help to make this realistic. Fixtures must have clearly indicated and positively located setup position with a goal of changing equipment over without the use of hand tools. This is possible primarily through mechanical means. The goal of model changeover is to be less than or equal to TAKT time.

Use sensors / signals to indicate fixture characteristic / position. The following photos illustrate the use of a multi-pin electrical connector, which accomplishes:

- Fixture characteristic indicated to the controller.
- Electrical connection of solenoids and sensors to the controller.
- Very short changeover time.

2.4.7 Avoid Adjustments

Design controls, tooling and fixturing with no adjustments or “fine-tuning” required. Don’t require operator judgment and trial runs to see if parts are good.

Mechanical design is the key to this topic. Mechanical design considerations include multiple stop positions, multiple jigs, etc. Designs should first consider mechanical error proofing. Any controls applied to error proofing must be implemented in a reliable fashion.

Other control considerations include:

- Mechanical design must consider fixed sensor positioning.
- Quick-change control components should be considered.
- Sensors (proximity, etc) should be used to detect tooling position rather than actuator position or part position.

- Self-teach control components should be considered.

2.4.8 Design for Flexibility to Future Changes

There are many reasons that a system must be designed for flexibility:

- Product design changes.
- Schedule changes.
- Production requirements change.

In section 2.2.3 it was noted that you could avoid paying for something you don't need by designing 'right-sized' components. Generally, designing for flexibility increases cost since the control system has to make provision for expansion.

However, designs can take into consideration what possibilities exist and various means of supporting that possible future changes *without actually providing them*. If some initial cost is required, it can be kept to the minimum necessary such that the important flexibility / expansion is included. Then at the time of the actual expansion, additional costs required for that change could be contained in the budget of the change.

For example: There exists *a possibility that a motion may be added to a machine in the future. If the operator panel is using pushbuttons, the design could allow space for buttons and lights pertinent to the added motion. The prints would show and call out the reserved space. The prints also label a few I/O points "reserved" for these devices. Therefore, everything to this point is merely on paper.*

During the concept/design stage, specific and general areas of possible expansion should be identified and called out.

Additionally, flexibility does not necessarily mean that each machine/station has capacity for expanded functionality. The 'system' should be flexible. This may require more or less machines or different configuration.

Try to make the process flexible such that these changes do not require machine control changes.

2.4 Zero-Defect Quality

Equipment designed to have zero defects supports one-piece flow by reducing variation in the system. One-piece flow also aids visual inspection. Defective parts should be removed from the process prior to increasing their value.

2.5.1 Provide Simple, Built-In Error Proofing

Error proofing methods must be used to eliminate potential sources of failure found in Failure Mode Effects Analysis (FMEA). Design fixtures and machines to detect abnormalities and to stop and signal automatically whenever they occur.

The system should be designed to assure bad parts do not flow down the good part path. This will prevent waste that would result downstream by working on the defective part. Mechanical error proofing should be given first priority because sensors add controls complexity, equipment downtime, machine adjustments, and diagnostics. Sensors can be easily defeated.

If bin sensors are required, consider stand-alone, teachable systems.

Review Delphi *Addendum*[6], subclause 21.2 for part quality back checking requirements for further information.

2.5.2 Consider Whether to Have Machine Detect Error, Reject Part and Alert Operator

Design equipment to detect errors and insure that machine rejected parts are contained properly and removed from the process. The equipment must alert the operator when this occurs and require a "non-normal" activity such as releasing the rejected part.

2.5.3 Support Standardized Work

The equipment design should make it difficult to deviate from standardized work. From a mechanical standpoint, this applies to equipment layout and parts organization. It also applies to posting of standard work instructions.

2.5.4 Boundary Samples

Boundary samples (marginally bad or good masters) are provided for the operator to verify that all test or verification systems are functioning properly.

2.5 Reliable and Maintainable

Slower, simpler machines designed to module TAKT times should be more reliable and therefore have less down time. However, recovery from failure must be designed for minimal time.

2.6.1 Equipment Designed for Planned Maintenance

Planned maintenance includes scheduled and unscheduled maintenance programs with strategies for responding to machinery and equipment failures.

The *Lean Equipment*[1] guideline discusses the "owner/operator concept". It is a concept whereby the operator of the machine assumes the role of owner with responsibility for the condition of the equipment.

The planned maintenance schedule should include the following:

- Equipment calibration.
- Verification of the safety equipment.
- Check the sensors that are not actuated each cycle.
- Routine maintenance could be indicated as a message on the HMI.

While developing the planned maintenance schedule on a machine bear in mind the following:

- Development / review of the calibration procedures.
- Review of the spare parts list(s).

2.6.2 Equipment Designed for Accessibility

Try to design the machine for easy access to control enclosures, hydraulic units, and pneumatic valves. However, recall that lean thinking is heavily production-focused. Therefore, where compromises or conflicts between maintenance and production become an issue, support of production needs to get the priority. In some cases this may lead to less than favorable maintenance situations.

Guards which are easily removable and support ease of maintainability, can create additional controls considerations:

- Generically speaking: the more frequently a guard has to be "removed" the more complex the control circuits which accommodate this.
- Note that lockout is required when non-interlocked guards are removed.

- If guards do not require a tool to remove, then safety will require that the guards be interlocked, and a risk assessment process should show the level of control reliability (complexity) which correlates to the "easily" removed guard.

Mounting the control enclosure to the rear of the machine clears it for improved accessibility for maintenance but this may also remove the lockout means from easy access by the operator.

For housekeeping, maintenance, and sound level issues, there are advantages to mounting the hydraulics separate from the machine. Refer to section 2.4.1 for related discussions.

2.6.3 Equipment Designed for Maintenance Diagnostics

Equipment diagnostics should be helpful and easily understood for both operators and maintenance personnel so that the equipment can be returned to production quickly.

- Visible and/or audible indication of maintenance required.
- Self-diagnosis and correction instructions.
- Identification of faults to component/module level.
- If needed, the machine should be capable of storing performance data.
- If providing data, the output should not be a proprietary format.
- Diagnostics should check for the change of state of sensors.
- Diagnostics should be designed to support production first, then other issues.

Production counters tied into the controller can be used to support preventive maintenance information. Note that software counters can be easily overwritten.

Conditions, which inhibit a machine from going into cycle, should be indicated to the operator ***before*** the machine cycle is attempted.

Historically, machine diagnostics detect a problem of a machine only *after* a cycle has started. Additionally diagnostics should inform the operator the cycle didn't start or why it won't start. The operator can immediately correct the problem prior to walking away to perform another task.

2.6.4 Consider Proper Use of Standardization

Design equipment to use components that are commercially standard, readily available, and common from machine to machine. This should reduce spare parts inventories and associated carrying costs.

"Approved" component lists are more specific than "preferred" components and need to be ready before equipment is purchased. The approved component lists should take into consideration the geographic destination of the equipment and what is available there.

Strict compliance to approved components lists has several advantages:

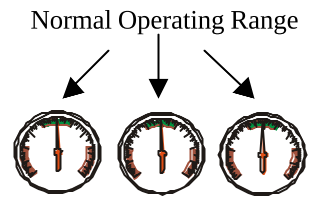
- Reduction of spare part inventory.
- Familiarity of maintenance personnel with components.
- Improved cost and support negotiated through quantity purchases.
- Shorter approval times and shorter deliveries.

However, compliance to approved components lists also presents some problems:

- Group purchases make buying per geographic location difficult.
- Applying ‘off-the-shelf’ principles increases spare parts inventory.
- Life cycle cost of the cell may make adherence to an approved list moot.
- Forcing suppliers to use unfamiliar components may result in…
    - ? Higher initial capital equipment costs
    - ? Lower machine quality and reliability

2.6.5 Information Management

A key to equipment maintainability is the availability and understanding of the necessary information. Once a master set of operating parameters is established one needs to be quickly informed of an abnormal condition and be able to return it to normal.



- Mark directions of rotation and flow.
- Label the enclosures and devices so major items can be found.
- Label critical components replacement part numbers (manufacturer’s, not supplier’s).
- Dirty filter indication and replacement part numbers labeled.
- Put a Machine Manual on the machine.
- Label normal operating ranges of gages, etc.
- Identify mechanical and electrical home position for diagnostic troubleshooting.

2.6.6 Use of Modular Components

Equipment should be designed into physically and functionally distinct units to facilitate their removal and replacement (e.g. gearbox, circuit board, drive unit). Fixing circuit boards, gearboxes, etc. often requires specialized skills, tools, and training while replacing an entire unit or module saves time and reduces the need for special training.

- Use quick disconnects for utilities whenever removal or replacement will be facilitated.
- Use standard vs. specialized electrical connectors.
- Be careful not to “overkill” the use of quick disconnection. They can become a high maintenance item themselves.
- Avoid misconnections by not using the same connector or gender more than once on a machine. (This does not apply to plug-in devices such as sensors and solenoids.)

Quick connectors can:

- ? Shorten replacement and troubleshooting times for high maintenance components.
- ? Facilitate easy removal of power source.
- ? Reduce the number of tools required.

3 EQUIPMENT DESIGN EXAMPLES

The examples of equipment provided in this section reflect the areas discussed in Section 2. Each example is evaluated from a lean perspective and comments listed, i.e. “Observations”. An indication of (+) means that comment is positive, (-) means it is negative, and (±) means it has positive and negative indications.

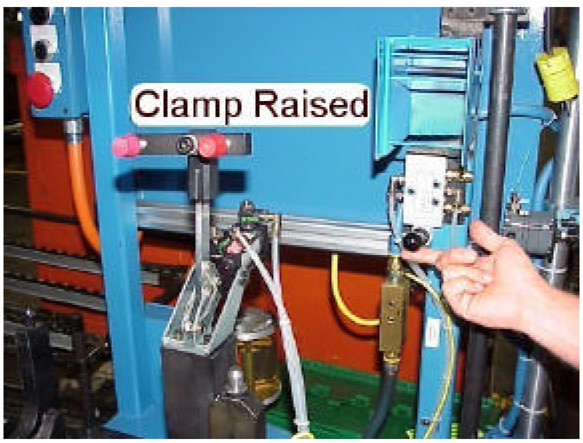
(See following pages.)

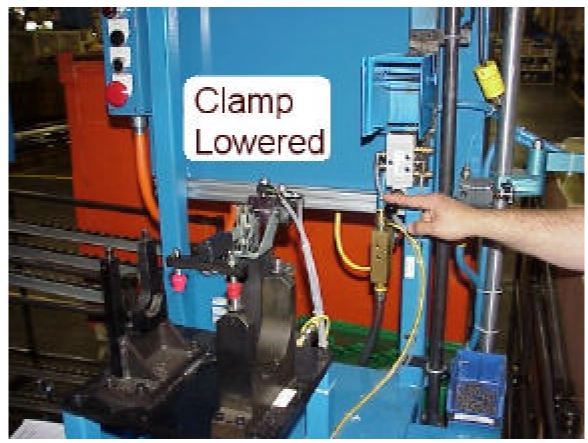
Example 1: Part Clamping Without Electrical Controls

Description:

The part clamp is set to a very low force and velocity. The clamp can easily be stalled throughout the motion until it comes into contact with the part. During the final few degrees of travel, mechanical advantage is used to provide appropriate clamping force.

There are no electrical parts in the design of the clamp. The operator pushes on a directional valve knob. However, the tools used by the operator require the control panel seen in the back of the machine. (Note: There is no PLC on this machine.)





Observations:

+ Minimal controls

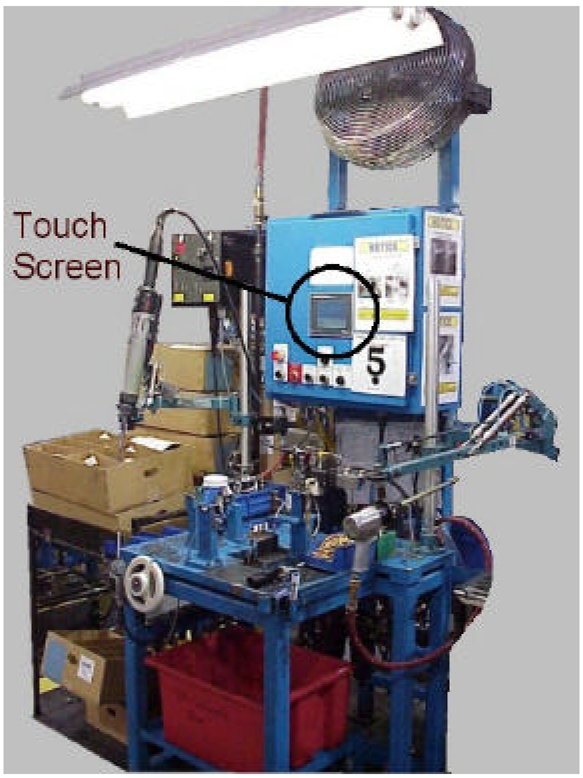
- Knob not mounted in an optimal ergonomic position

- Safety subject to regulator and flow control settings

Example 2: Main Enclosure & HMI Combined

Description:

The enclosure is mounted facing the front of the machine. Operator machine controls are mounted in the door of the enclosure. Main electrical supply is 120vac.



Observations:

+ Eliminates an enclosure for the HMI.

+ Uses 120vac supply.

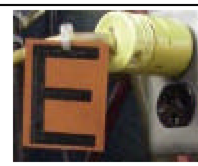
+ Uses pneumatic quick disconnect.

- Operator reaches over machine for HMI.

- HMI is slightly too high.

- If guarding were required it would probably block the enclosure.

± This demonstrates how a layout supports production first while supporting maintenance second. Electricians are required to reach over the machine to perform trouble shooting.



120VAC Supply

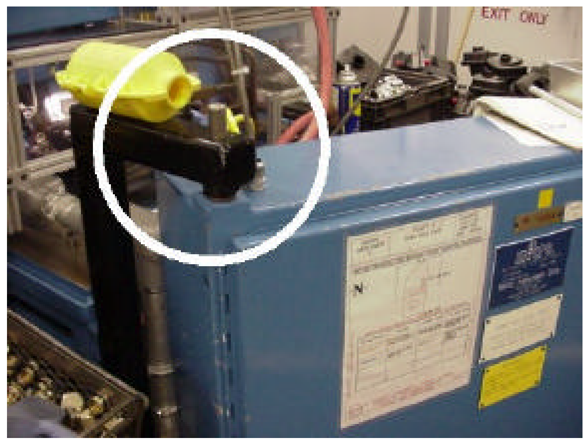
Lockout Box

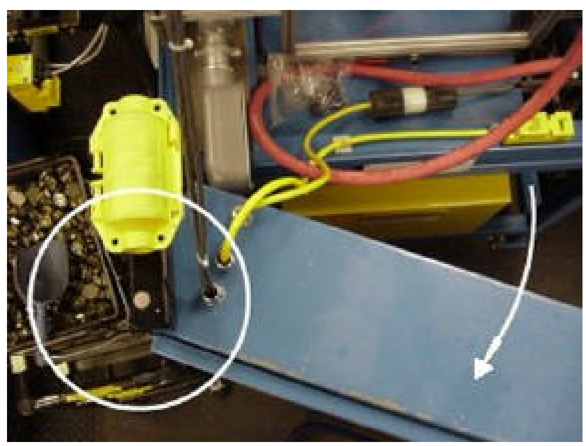
Example 3: Pivot Enclosure for Maintenance

Description:

The enclosure is mounted low on the back of the machine. To gain maintenance access, the enclosure pivots out of the way. A lockable latch is provided to retain the enclosure in its 'home' position.

Additionally, the machine uses a lockout box for the 120vac main supply plug.





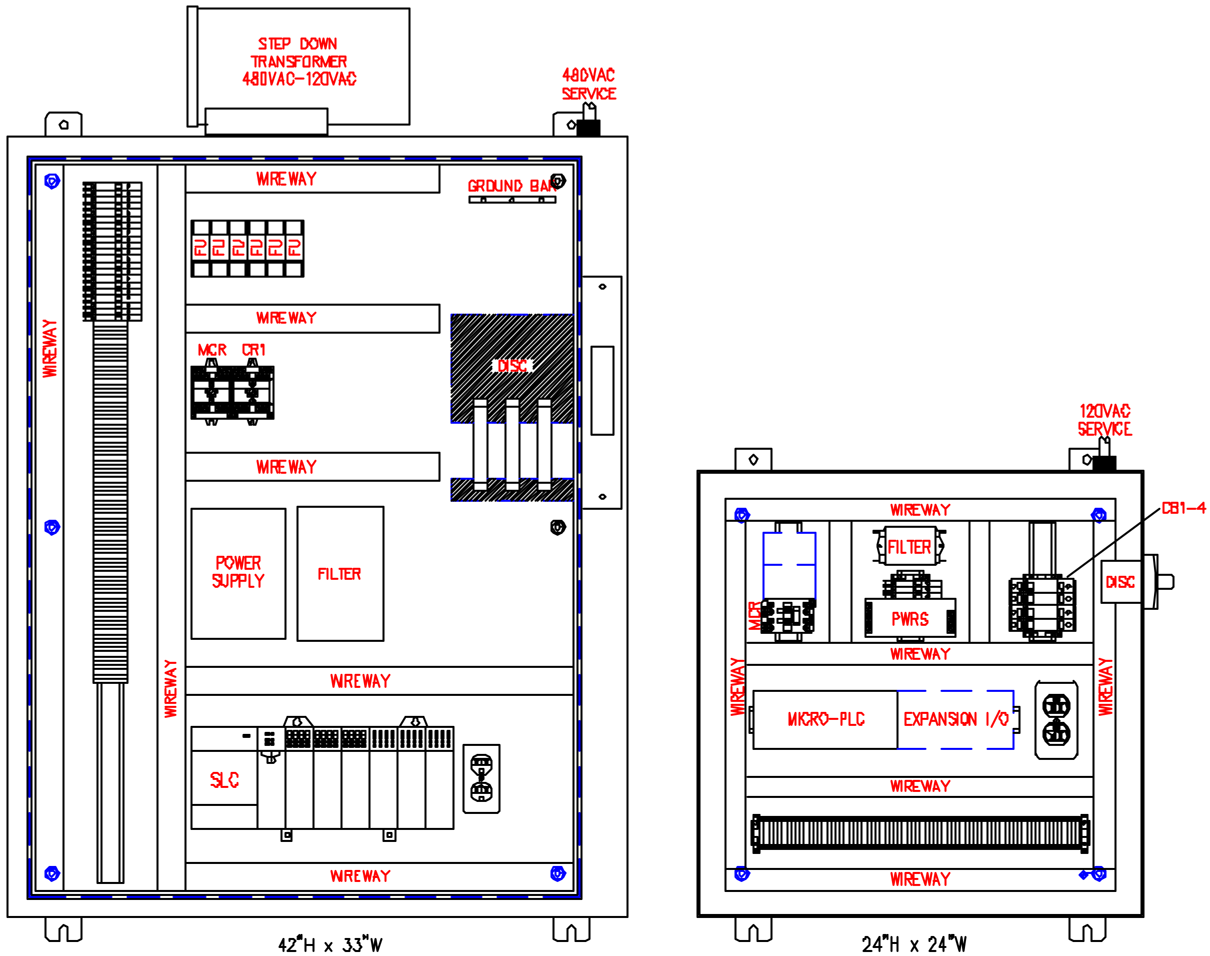
Observations:

+ Enclosure mounted on rear of machine.
+ Main supply is 120vac using plug and lockout box.
- Pivot hardware cost if unnecessary.

Example 4: Electrical Enclosure Designs

Description:

Each panel has been designed to control the same piece of equipment but the size has been reduced from the traditional design to the lean design due to use of IEC versus NEMA components and use of rotary style disconnect instead of traditional flange mounted disconnect. Spare space has also been reduced.



Traditional Observations:	**Lean Observations:**
- 480vac 3-phase service	+ 120vac service, smaller disconnect
- Spare capacity may never be used	+ Unnecessary capacity not included
	+ Easier to mount on back of machine
	+ Small components (meet the needs)

Example 5: Rotary Disconnects

Description:

Depending on the situation, a typical flange-mounted blade disconnect can occupy a large percentage of an enclosure and be very costly. Hence, many 120vac (or less) applications are utilizing rotary-style disconnects (and other styles) to provide leaner controls.

Note: Any supply voltage above 120vac (nominal) requires door interlocking.

A

B

C *(see below)*

D *(see below)*

Observations:

\+ 120VAC used as primary supply.

\+ Rotary disconnect saves space and cost.

\+ Side (end) mounting is preferred. (A & B)

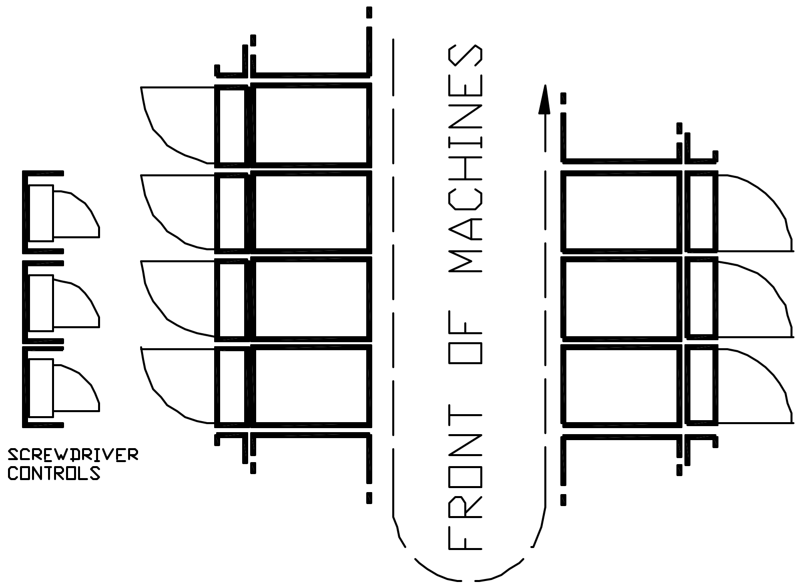
Make sure the application meets all Delphi specifications:

- (C) This disconnect actuator is not in control of the switch at all times. (Addendum[6], article 7.10.5)
- (D) This disconnect is lockable in both ON and OFF positions. This is a violation of NFPA79[5], article 7.10.3.

Example 6: Maintaining Narrow Machine Width

Description:

The operators in this cell use torque monitoring nut drivers. The controllers for these tools are mounted on a simple mounting stand behind the machines. They have their own power supply. Dry contact interface signals connect to the station's PLC and safety circuit through cable connectors.



Screw Driver Controls

Observations:

+ Individual machine width minimized.

+ Separately mounted enclosures allow for floorplan flexibility.

+ Dry contact interface provides isolation.

- Difficult to see the torque controller display while operating machine.

- Increases rearrangement time.

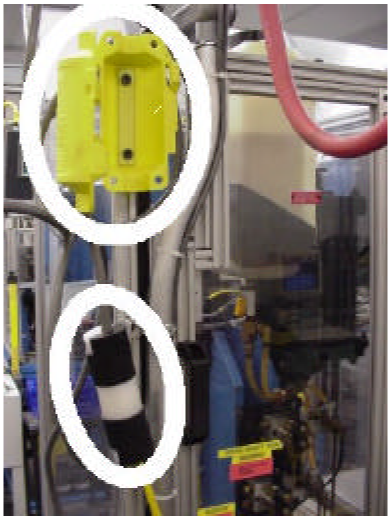
- Transformer mounted below the 16" limit.

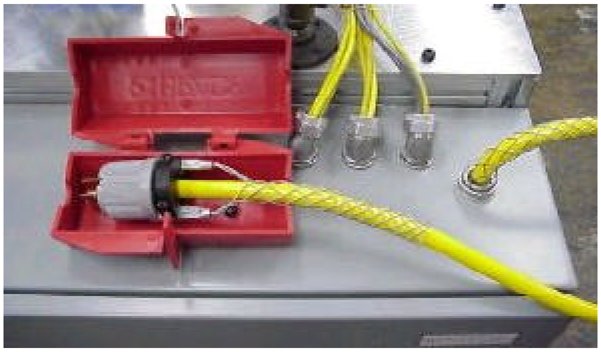
- Keypad and pushbuttons mounted too low.

Example 7: Lockout Plug Box

Description:

After the plug is disconnected from the mating receptacle thus removing (120vac) power from the machine, the plug is then placed inside the lockout plug box, which is then closed. A lockout device is then placed on the box so that the plug cannot be removed from the box and reinserted into the mating receptacle until the lockout device has been removed.





Observations:

+ Eliminates the requirement of a lockable disconnect on the enclosure.

+ Cost effective.

Note: Although it is not necessary, some divisions may still require an enclosure mounted disconnect.

Example 8: Small HMI's

Description:

By definition, the term "HMI" (Human Machine Interface) typically applies when there is a touch panel or other programmable device. In addition, there is always a requirement for some hard-wired devices. In a lean machine, the number of devices will be at a minimum.

A

B

C

Observations:

+ Small HMI's allow for more mounting and location options. (C)

+ Fewer components result in less maintenance. (B & C)

+ Small pushbuttons (that are not too small).

+ Programmable HMI's with few pushbuttons promotes standardization. Future changes are accomplished more easily than hardwired devices.

- Could some components be eliminated by using the programmable screen? (A)

- Documentation is more difficult to decipher than a hardware panel schematic.

± Color displays are ergonomically better but much more expensive.

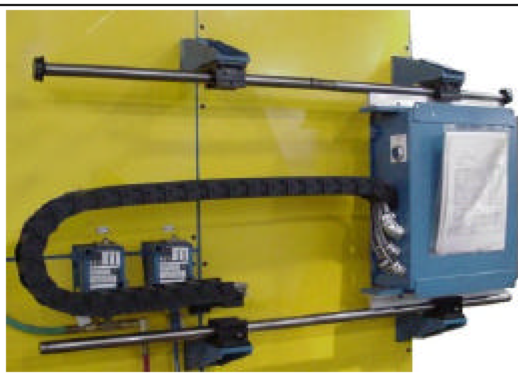
Example 9: Slide Out HMI Enclosure

Description:

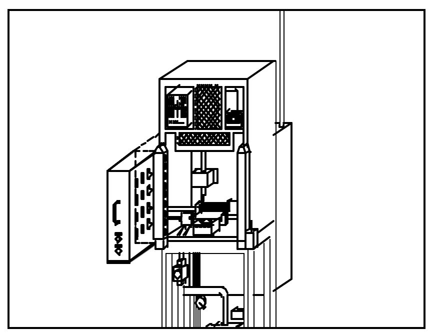
In order to enable minimal machine width, a pushbutton enclosure could be mounted on a slide out. These machines use Thompson slide bearings to provide maximum reliability. One emergency stop pushbutton is mounted on the end (C) for accessibility when the enclosure is retracted. In addition, an emergency stop pushbutton is mounted in front of the operator in a dedicated enclosure or the face of the HMI enclosure. Conductors are captured in large flexible conduit to provide very long reliability and good flexibility.

A: Flexible Conduit

C



B: Wire Track



D

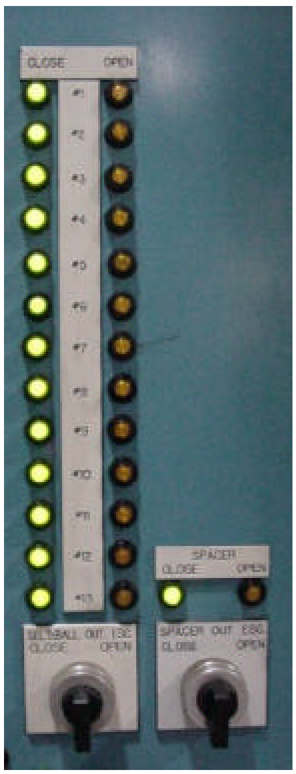
Observations:

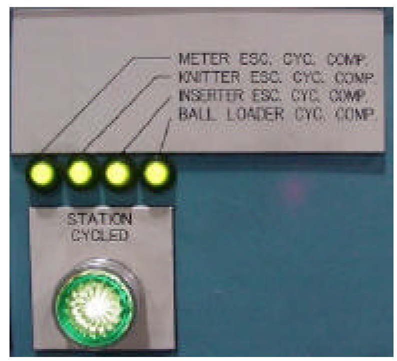
+ Supports narrow machine goals.
- Cost of hardware (especially when other options are available).
- Operator tendency may be to leave in the extended position.
- In this example, the large quantity of pushbuttons and lights should be replaced with an HMI.
- Mounting devices on the same end as the hinge is discouraged in general.

Example 10: LED Pilot Lights

Description:

This cell used LED’s as pilot lights on the pushbutton boxes in conjunction with selector switches and simple two-line message displays. The displays were used for machine diagnostics and operator pacing. The LED’s were used for position and status indication.





Observations:

- If ‘bulb test’ is required, then a pushbutton must be added.

± The color and state were not difficult for the operator to distinguish.

\+ LED’s last much longer than incandescent bulbs.

\+ In multiple-state cases, the LED’s require less space compared to pilot lights.

± In two-state cases, the selector switch and two LED’s use the same space as two illuminated pushbuttons. (Unless multi-color LED’s are used.)

Example 11: Task Lighting

Description:

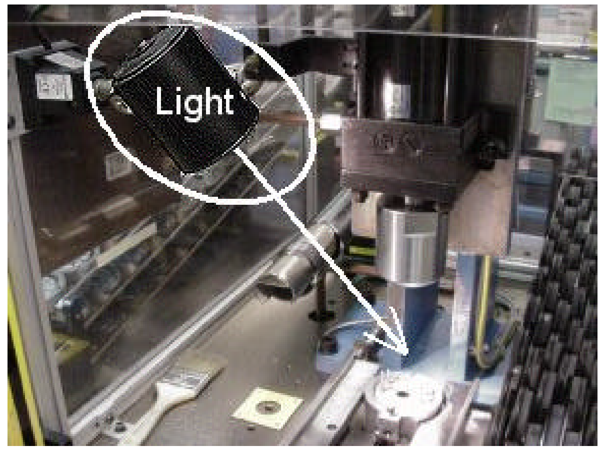
The light provided on this machine is relatively focused at the point of need and doesn't flood the whole area. The lamp base is adjustable and is not in the way of the operator.

Observations:

+ Task lighting, which moves with the machine.

+ Light provided where necessary.

- Still need to provide ambient lighting.



Example 12: Tight Floorplan

Description:

These machines are narrow thus minimizing walking distance for the operators. Not shown in the photo are several machines on the left, which complete an overall "U" shape. In order to change production, operators are added or subtracted.

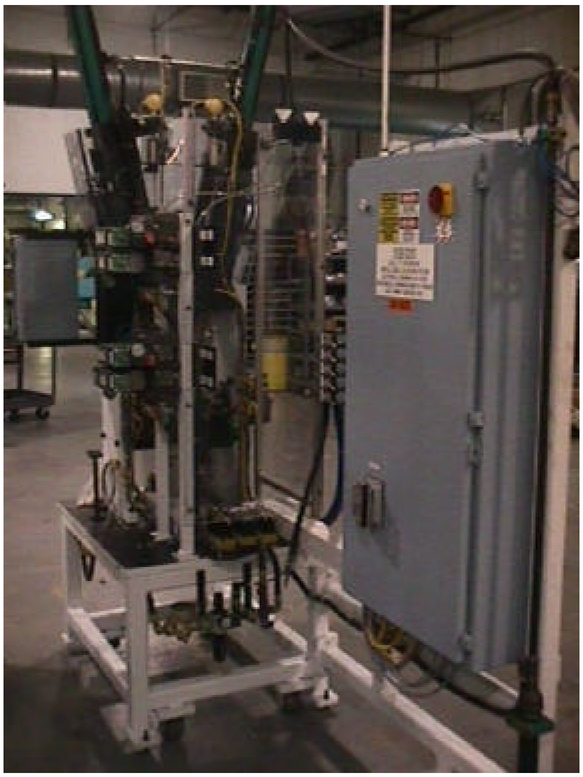
Observations:

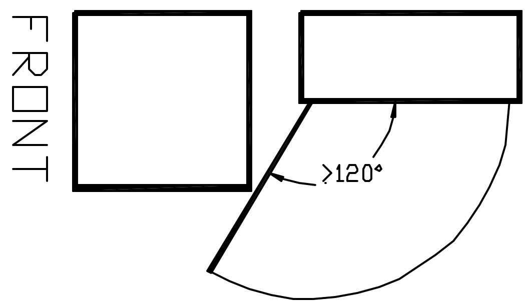
+ Task lighting, which moves with each machine.
+ Small, simple, and common HMIs.
+ Wobble sticks for cycle initiation and mounted for operator efficiency.
+ Enclosures mounted on the back.
+ Flex drops for both electric and air.
+ Self-contained.
+ Side access is not required.
+ Operator instructions are meaningful and available.
- Not C-frame leading to more operator motions

Example 13: Perpendicular Enclosure

Description:

In order to accommodate the control requirements of a machine, the control enclosure may be too large to mount directly to the rear of the machine. Therefore, it can be mounted perpendicular to the rear of the machine using attached support. Other choices may not be as appropriate.





Observations:

+ Overall machine width kept to a minimum.

+ Direct wiring is still possible.

+ Full access around the maintenance points.

+ The disconnect handle is in control of the switch, which is mounted on the door. (*Addendum*[6] subclause 7.10.5)

+ The door swing is greater than 120°. (*Addendum*[6] 11.6.3.)

- Incorporation into another cell in the future may be limited due to depth.

- Portable (wheels) but difficult to pickup with a fork truck.

Example 14: Enclosure Supports Narrow Machine

Description:

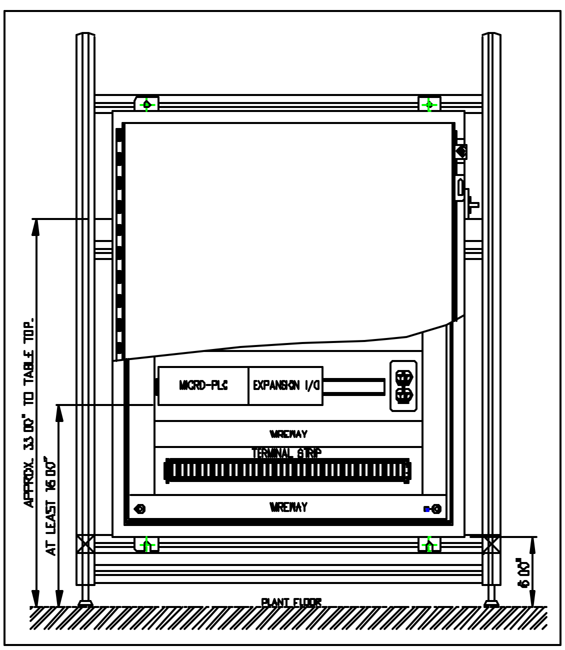
Lean vision is a narrow machine (for example, 36") with its main control enclosure mounted behind the machine. Per *Ergonomic Guidelines*[7], the work surface level is 32.7". Each example maintains enclosure components mounted above 16" and termination above 8" from the servicing level. . In order to conform to *NEC*[13] Article 110-26, item (e), parts feeders must be constructed to easily swing out of the way.

Example 1:

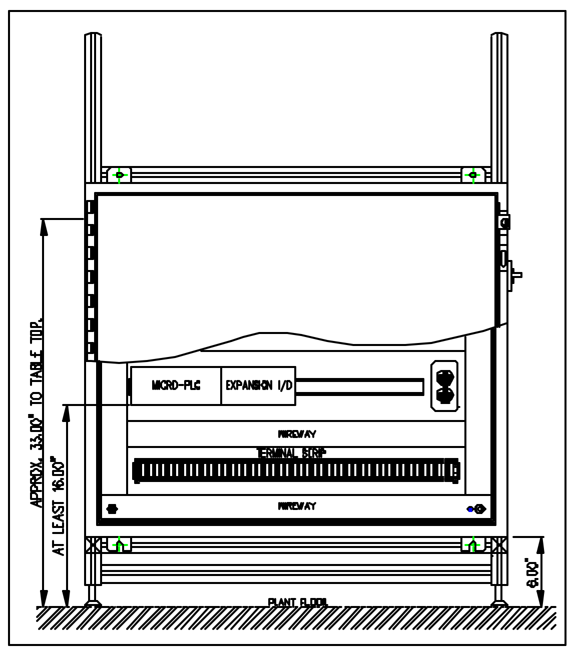
- *The enclosure is 36"h x 30"w.*
- *Part feeder presentation devices will probably need to be mounted on either side leading to a relatively wider machine.*

Example 2:

- *The enclosure is 30"h x 36"w.*
- *Parts feeder(s) can more easily be mounted over the enclosure resulting in a relatively narrow machine.*



EXAMPLE #1



EXAMPLE #2

Observations:

(+)..Enclosures mounted behind the machine.

(+)..120vac, 20amp primary service.

(+)..Example 2 better suited for passive parts feeders.

References

[1] *Lean Equipment Design*, Delphi Automative Systems, October 22, 1998
[2] *Delphi Automotive Manufacturing System and Implementation Guide* Sept. 1997
Book 1 *Employee Environment and Involvement*.
Book 2 *Workplace Organization*
Book 3 *Quality*
Book 4 *Operational Availability*
Book 5 *Material Movement*
Book 6 *Flow Manufacturing*
[3] *Delphi Manufacturing System Design Manual* Oct. 1997
[4] *A study of the Toyota Production System,* Shigeo Shingo, Productivity Press, 1989
[5] *NFPA 79 Electrical Standard for Industrial Machinery*, 1997 Edition
[6] *Delphi Electrical Specification for Industrial Machinery Addendum DA2004*, March 1997
[7] *Delphi Manufacturing Ergonomics Guidelines,* August 1999
[8] *Delphi Hydraulic Fluid Power – General Rules Relating to Systems Addendum DA2002*, Sept 1998
[9] *Delphi Pneumatic Fluid Power – General Rules Relating to Systems Addendum DA2003*, Sept 1998
[10] *Delphi Application Guideline for Safety Circuits*, September 1998
[11] *Delphi Design In Health and Safety Specification*, month year
[12] *Delphi S Andon Training Publication, September 1996*
[13] *National Electrical Code (NFPA 70-1999) a.k.a. "NEC"*
[14] *Specification for the Application of Light Curtains (December 1994, GM-1945)*

Suggested Readings

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Delphi-S Andon Training Publication. September 1996
Quality Network Quick Setup Manual QN-777
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