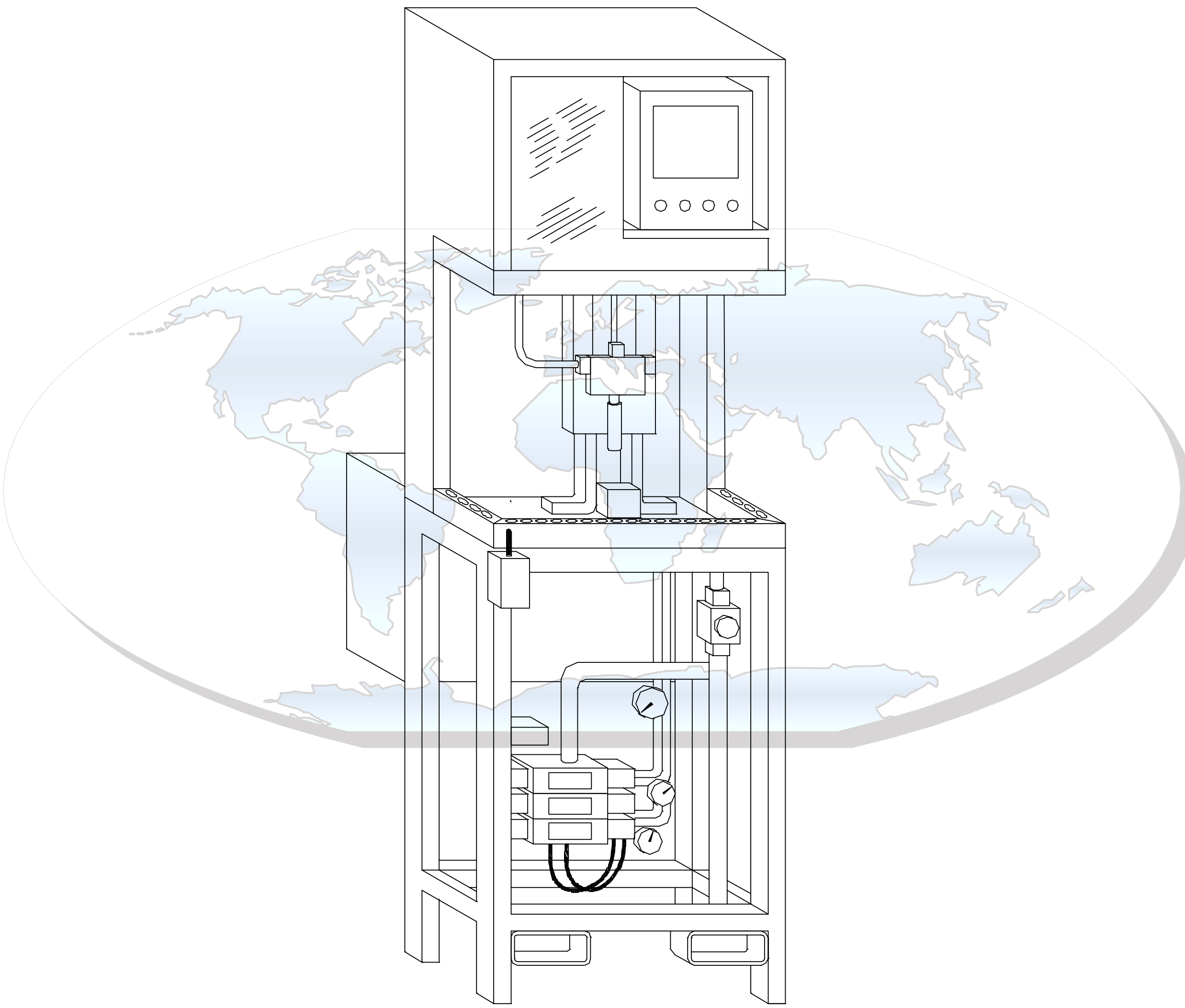
LEAN EQUIPMENT DESIGN



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LEAN EQUIPMENT DESIGN

First Edition Issued May 27, 1998; 2nd Print October 22, 1998

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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 Design. It was prepared in conjunction with the Manufacturing System Design (MSD) manual to provide additional equipment design characteristics that support the process goals of:

- 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.

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Grammatical Error corrected, not noted; 2nd Print

1. Introduction

1.1. Purpose

This manual is intended to provide guidelines for equipment design that will enable the implementation of the Delphi Manufacturing System (DMS)[1] and which are consistent with the principles outlined in the Manufacturing System Design (MSD) manual[2].

This is accomplished by:

- Showing the Relationship to PDP
- Identifying the Relationship to the six interdependent elements of DMS
- Reviewing Manufacturing System Design Concepts
- Identifying Guidelines for Equipment Design Characteristics
- Providing Examples to Reinforce the Concepts
- Providing a Lean Equipment Checklist

> Note: Whenever you see the symbol, it indicates an idea starter to prompt further thought or consideration.

1.1.1. Relationship of Equipment Design and PDP

Delphi PDP98 has been updated to show the relationship between the Delphi Product Development Process and the Delphi Manufacturing System as well as QS-9000. The following PDP98 tasks are directly supported by the guidelines contained in this manual.

In CD-PS-010, Create Manufacturing Process/System Concepts, application of these guidelines will help in completion of the following tasks and sub tasks:

CD-PS-010-060	Develop initial requirements for the manufacturing process/system concepts
CD-PS-010-060-020	Develop initial equipment requirements
CD-PS-010-060-030	Develop initial tool and gage requirements
CD-PS-010-060-040	Develop initial manufacturing facility requirements

The concepts created in CD-PS-010 are enhanced to become the initial Manufacturing System Design (CD-PS-025) and Manufacturing Process Design (CD-PS-40). Application of these guidelines will help in completion of the following tasks and subtasks:

CD-PS-025-040	Develop initial operator workplace design
CD-PS-025-050	Initiate material handling design
CD-PS-025-120-020	Develop initial manufacturing facility designs for prototype and production
CD-PS-040-020-030	Develop initial design of equipment for prototype
CD-PS-040-020-050	Develop initial design of tools and gages for prototype
CD-PS-040-030-050	Develop initial design of equipment for production
CD-PS-040-030-070	Develop initial design of tools and gages for production

The initial designs are updated in similar tasks, in Update Manufacturing System Design (CA-PS-005) and Update Manufacturing Process Design (CA-PS-014).

Designs are completed and/or specifications for design and build of equipment and tools are issued in similar tasks, in Finalize Manufacturing System Design for Prototype (FA-PS-005), Finalize Manufacturing Process Design for prototype (FA-PS-014), Finalize Manufacturing System Design for Production (FA-PS-025) and Finalize Manufacturing Process Design for Production (FA-PS-034). Particular tasks of interest are:

FA-PS-034-010	Finalize Manufacturing process requirements and designs for production
FA-PS-034-010-020	Finalize requirements and create specifications for production equipment
FA-PS-034-010-040	Finalize requirements and create specifications for production tools and gages
FA-PS-034-020-030	Finalize design of equipment for production
FA-PS-034-020-050	Finalize design of tools and gages for production

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 material resulting in:

- Maximum utilization of operators' skills and attention
- Properly sized modules
- Smooth flow of materials (no process islands)
- Minimum Total Life Cycle Cost of the products produced

Our 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. This allows equipment to be arranged to effectively utilize floor space and people in order to be responsive to customer requirements.

A fundamental principle in the design of manufacturing systems is the elimination of waste and cost. All people involved in the equipment design, specification, selection, or build must have an understanding of the types of waste and be involved in their reduction and elimination.

Figure 1 below shows the seven types of waste, commonly found in our manufacturing processes.

Identification and Elimination of Waste

Types of Waste	**Contributors to Waste**	**Ways to Reduce Waste**
1. **C**orrection	1. **U**nevenness	1. **S**implify
2. **O**verproduction	2. **O**verburden	2. **C**ombine
3. **M**ovement of Material	3. **C**urrent Process Methods	3. **E**liminate
4. **M**otion		
5. **W**aiting		
6. **I**nventory		
7. **P**rocessing		

Figure 1

1.2.1. Process Requirements

To meet this goal, Delphi has established seven Process Requirements for Manufacturing Systems shown in Figure 2 below. Sections 2 and 3 of this manual contain guidelines for, and examples of, equipment characteristics necessary to meet these requirements.

PROCESS REQUIREMENTS

• **Lean:**	Eliminate all waste. Minimum amount of equipment, inventory, people and lead time
• **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
• **Customer Focused Modules / Cells:**	Capacity based on a single customer or small grouping of customers
• **Material Transfer:**	One piece / Small lot
• **Material Flow:**	Value added to value added operation
• **TAKT Time:**	Available productive time / quantity required
• **People:**	Engaged, adding value, safely

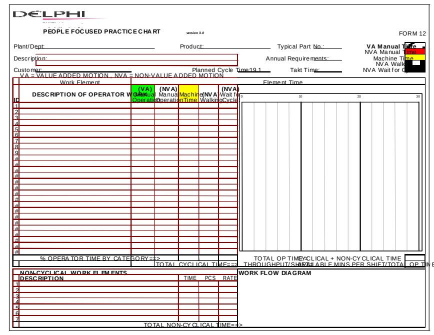
Figure 2

1.2.2. System/Cell Design Goals

There are several system/cell design goals that equipment design supports. These goals are:

- Flow material through the cell
- Have the ability for one person to run the cell efficiently
- Keep material outside the cell. Parts are loaded into the cell from the back of the cell
- Locate material to minimize handling/optimize presentation to operator
- Arrange equipment to have operator start and finish points close together
- Size equipment to minimize operator walk distance
- Never have an operator wait on a machine (more than 3 sec) to finish cycling
- Non-cyclical work is done outside the cell by support people
- Cells should be capable of benefiting from continuous improvement at least every 30 days
- Utilize manual load/auto-unload to improve balance and work flow

Use a PFP chart (right) to document operator standardized work. This is the key to continuous improvements. (Refer to Book 6 of Reference (1) for a copy of the PFP chart).



1.3. Review of Manufacturing System Design (MSD) Methodology

The method for creating manufacturing systems design is documented in the Manufacturing System Design (MSD) Manual[2]. The MSD methodology is a team/workshop approach, which consists of the following steps:

1.3.1. Determine Module Size

Module size is based on customer requirement. The focus is on more small modules to be flexible to variation.

1.3.2. Calculate TAKT Time

TAKT Time is based on customer demand. It provides us with the target rate for material consumption.

TAKT time per module is calculated as:

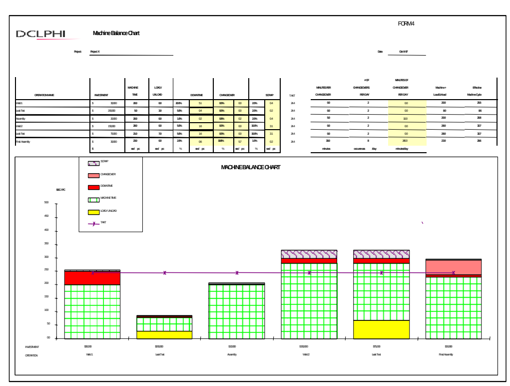
$$\text{TAKT Time per module (sec/pc)} = \frac{\text{Available Operating Time (sec/day)}}{\text{Daily Volume Required (pcs/day)}} \times \text{(No. of Modules)}$$

1.3.3. Construct a Block Diagram

Construct a block diagram identifying all steps required to produce the part and lay them out in a process flow order.

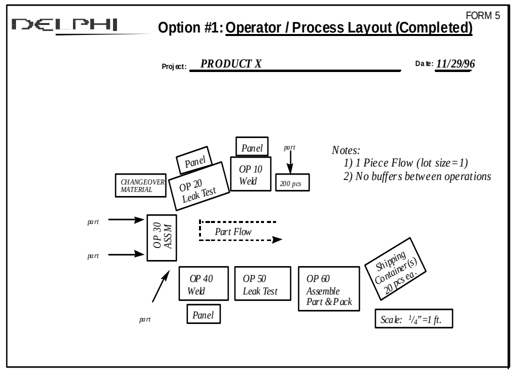
1.3.4. Prepare a Machine Balance Chart

Utilizing the block diagram, prepare a machine balance chart to compare the effective cycle time to the TAKT Time.



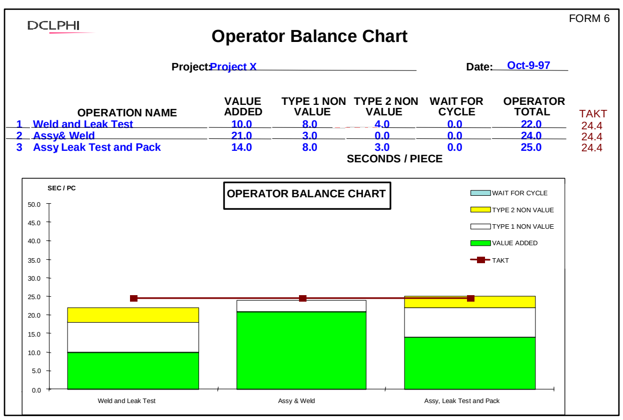
1.3.5. Lay Out the System

Lay out the system to optimize value added activity. Arrange equipment to facilitate material flow and support the operator with value added motions. As machines are designed, operator panel and control enclosure locations, material racks, and cycle initiation devices are all added to the layout.



1.3.6. Prepare an Operator Balance Chart

Prepare an operator balance chart showing the work content of each operator designated as value added or non-value added. The goal is to have the minimum number of operators necessary to perform the value added activity at the customer rate.



FORM 6

Operator Balance Chart

Project: Project X Date: Oct-9-97

	OPERATION NAME	VALUE ADDED	TYPE 1 NON VALUE	TYPE 2 NON VALUE	WAIT FOR CYCLE	OPERATOR TOTAL	TAKT
1	Weld and Leak Test	10.0	8.0	4.0	0.0	22.0	24.4
2	Assy& Weld	21.0	3.0	0.0	0.0	24.0	24.4
3	Assy Leak Test and Pack	14.0	8.0	3.0	0.0	25.0	24.4

SECONDS / PIECE

1.3.7. Determine Buffer Sizes, Lot Sizes and Lead Time

Once the system is laid out, buffer sizes and lot sizes can be determined. With this information, lead time can be determined.

1.3.8. Determine Containerization and Packaging Requirements

Determine containerization and packaging requirements for material to flow to the point of use, from operation to operation, and to the customer.

1.3.9. Error-Proof the System

Error-proof the system by considering material movement and storage between operations, part labeling, and routing of rework and scrap.

1.4. System Simulation and Mockup

Simulation is a decision-support tool that allows us to construct and analyze a computer model that imitates a real system. Simulation is an integral part of concept design which, when done early enough in the system design, can have a significant impact. Typical information obtained includes:

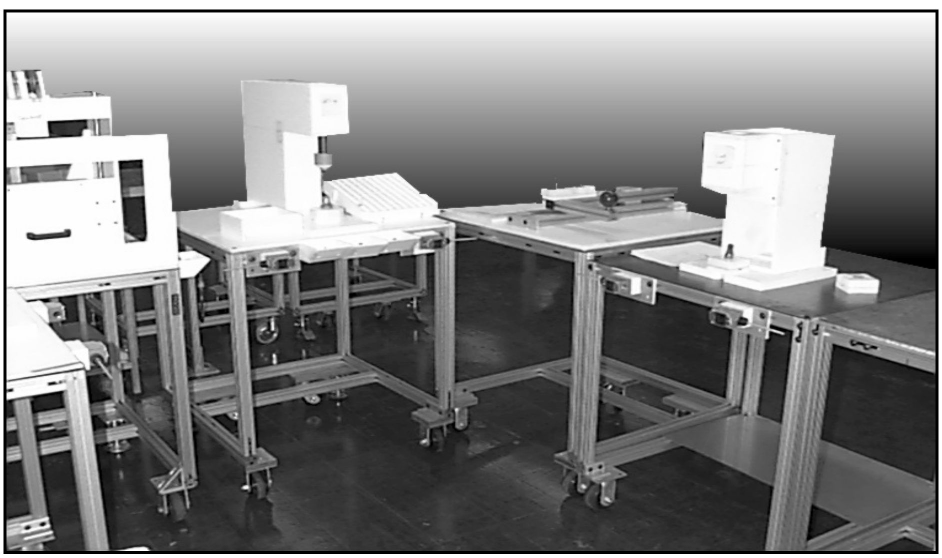
- System Throughput
- System Constraints
- In-Process Buffer Sizes
- Number of Resources Required
- Number of Carriers Required
- Improvement Options

As in most computer models, the accuracy of the output is dependent upon the availability and accuracy of the data used. Typically, breakdown and repair data are the most difficult to obtain.

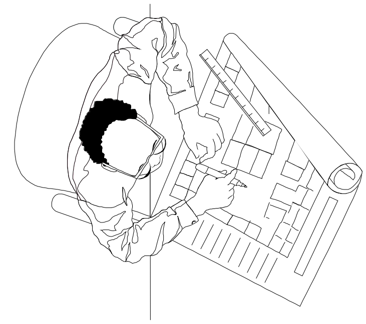
Simulation software approved for use within Delphi:

- WITNESS
- SIMAN/CINEMA
- AUTOMOD
- C-MORE/MACH2
- THE GM TIP TRAINING

A mockup is a physical 3-D model that allows people to touch it, try it out, and play "what if?" unlike a 2-D drawing. Mockups of machines, equipment and part presentation devices allow us to validate and improve the operator-machine interface. Mockups are typically Creform and foam board representations that allow cross functional teams and vendors to eliminate potential problems before building the equipment. Our goal is to identify and eliminate sources of waste through operator input and involvement.



2. Equipment Design Guidelines



Making the transition to lean manufacturing equipment can be difficult, for it runs counter to our tendency to improve a manufacturing system by automating as much as possible and speeding up the machinery. To move material in a continuous, "balanced" flow may mean using or developing slower, simpler, less-automated machines.

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

Using the Lean Equipment Checklist

These characteristics and the rationale for how they support the system will be explored in subsequent sections. Each section of the guidelines is supported by a **Checklist** section (Appendix A). The Checklist, a section of which is shown in Figure 3 below, is a tool to be used to ensure the guidelines were adequately considered. It is made up of a series of questions and answers. The choices of answers go from "most preferred" on the left to "least preferred" on the right. The comments section is provided to explain why the "most preferred" method may not be possible.

LEAN EQUIPMENT CHECKLIST

2.4 PORTABLE/FLEXIBLE

DESCRIPTION	REFERENCE	ANSWERS			COMMENTS
2.4 How long does it take to move the equipment, good part to good part?		0-4 hrs.	4-8 hrs.	>8 hrs.	
2.4.1 Is machine self contained? (control panels, hydraulics, coolant systems, chip systems, leveling method, vibration isolators, etc.)	Integral frame with all auxiliaries attached.	Yes		No	
2.4.2 Is this a "flat floor" installation?	No pits!	Yes		No	
2.4.3 Can the machine be installed without fastening to the floor?		Yes		No	
2.4.4 Are fork pockets and/or casters included in equipment?		Yes		No	
2.4.5 Are utilities and ventilation systems connected with flexible drops and quick disconnects?	Delphi Controls COE	Yes		No	
2.4.6 Have rollover or interchangeable fixtures been incorporated in the design?		Yes		No	
2.4.6 How long does it take to changeover? (Good part to good part.)		<10 min.	10-15 min.	>15 min	
2.4.7 Have adjustments been eliminated for set-ups and changeovers?		Yes		No	
2.4.8 Is the machine design flexible enough to accommodate potential product design changes or new products?		Yes		No	

Figure 3

2.1. Supports the Operator

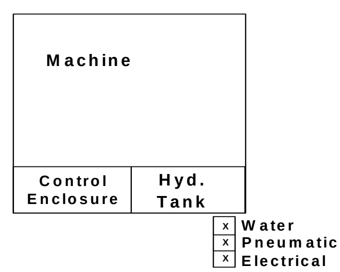
As stated in section 1.2 it is important to maximize the utilization of operators' skills and attention. Operators are the most important element in a lean manufacturing system. When operator functions are value added everyone wins. Operators should be doing value added work, not just watching equipment run. Keeping parts flowing smoothly with no interruptions is a difficult challenge. Helping the operator meet this challenge means providing equipment with safe effective guarding and everything within arm's reach, from shoulders to waist. It also means designs that provide the operator with immediate feedback on the status of the entire system and provide immediate knowledge of whether the work has been done right.

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. There are several tools available such as the Delphi Ergonomic Wall Worksheet[2], the Delphi Ergonomics Manual[3] and GM Standard ERG 1.0[4] that focus on identifying and eliminating Ergonomic Risk Factors.

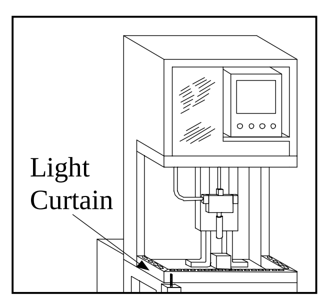
2.1.1.1. Proper Lockout Placement

To improve productivity, safety, and serviceability, place machine lockouts together in a central location, preferably at the rear of the machine.



2.1.1.2. Simple But Effective Guarding

The proper use of guarding can make both the operator and the machine more efficient. The proper mix of hard guarding, light screens, safety floormats, sliding barriers, and shuttle mechanisms to protect but not obstruct the operator during load, unload or equipment operation is essential.



Have your equipment concept drawings include guarding, wiring, pneumatics, operator panel, control enclosure, and cycle initiation devices to facilitate operator interface. Equipment concepts should not be approved without these features documented.

2.1.1.3. Equipment Addresses All Ergonomic Issues

Equipment design can either create or solve ergonomic issues. The following list of ergonomic guidelines should be considered when designing equipment.

Selected Ergonomic Guidelines Related to Equipment:

1. Set the work height to:

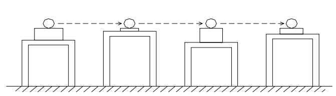
   For parts < 2 lbs. -- 4” above elbow

   For parts < 10 lbs. -- level with elbow

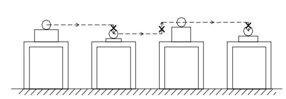
   For parts > 10 lbs. -- 4” below elbow

2. Make reach distances within 2 ft. if possible.
3. Use gravity: don’t oppose it.
4. Minimize the degree of spread of parts, fixtures, and disposal points.
5. Eliminate sharp edges on work surfaces.
6. Minimize vibration levels.
7. Provide good visual access.

Consider a common work height as shown below. Using a standard work station height often doesn’t consider the fixture thickness. This leads to variation in work height, and wasted motion in positioning parts.



Good



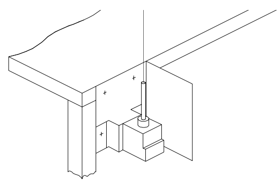
Bad

Design for average height in the country.

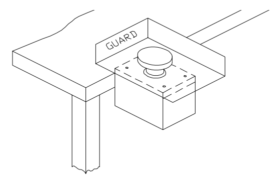
Consider other assist devices (e.g. lift tables) to position parts or containers for ease of loading/unloading

2.1.2. Select Proper Cycle Initiation

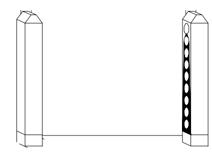
To make the operators more efficient they must be able to initiate the cycle, and move to the next operation with minimal or no wasted motion. Equipment can safely be started with a variety of devices, in many configurations, when done in conjunction with guarding. Some of the devices used include: whisker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



Whisker Switch



Palm Button



Light Curtain

Two (2)-hand initiation is a configuration where an operator must use both hands to operate buttons or switches for the entire machine cycle. This may be used for very short machine cycles to avoid the cost of other guarding.

One (1)-hand initiation is a configuration where an operator, in conjunction with a light curtain, automatic barrier guard, or a safety floor mat, can hit a button or switch while walking away from the machine. Whisker switches are often preferred because it is easy for the operators to position their hands without looking (waste of eye movement) for the switch.

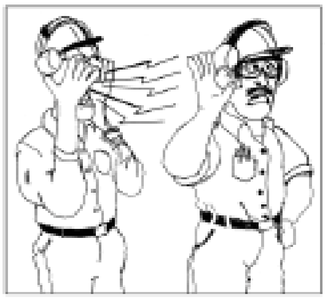
PSDI or Presence Sensing Device Initiation is a configuration that uses the light curtain to initiate the machine cycle. With this configuration, the operators simply remove their hands from the machine and the cycle starts.

Another configuration uses a switch in conjunction with a slide or door. With this configuration the operator pushes a slide into the machine or closes the door. This motion then triggers a switch which initiates the machine cycle.

Place cycle initiate switch along operator walk path and within reach.

If cycle time is < 3 seconds, the operator(s) will not be able to run multiple machines. In this case, two-hand cycle initiation with no light curtain may be more cost effective.

2.1.3. Reduce Machine Noise

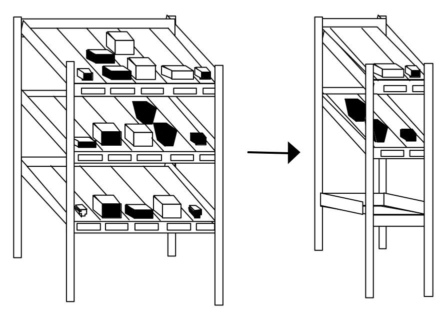


A lean machine needs to be a quiet machine. Operators on the plant floor need to hear and converse with each other (and with maintenance and other support staff areas) constantly to solve production problems and implement improvements in the process.

- Air/Oil is less noisy than hydraulic.
- Sound proof chutes - (part obtain/part disposal).
- Limit height of fall and angle of gravity chutes.
- Plexiglas and acoustical matting on drop shelves.
- Utilize reduced noise compressed air nozzles.
- Enclosures around part orientators/selectors.

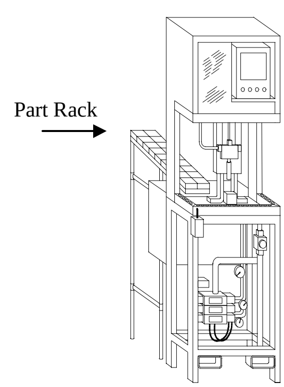
2.1.4. Simple Part Presentation Devices

Part presentation devices should be reusable, re-configurable and/or flexible. The illustration at right shows a part presentation rack reconfigured to present fewer parts with a chute to dispose of empty containers. Part presentations devises should 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.



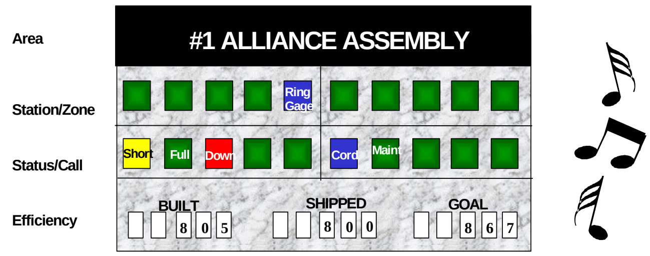
Before After

- Integration of part presentation devices with machine base and tooling should occur before guarding, piping, wiring, operator panel, and control enclosure location are finalized.
- Part presentation devices should provide FIFO (first in/first out).



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 (See figure above). The key to an Andon system is to aid in communication 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 Reference (5) 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 4 at right). 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 (see Figure 4 at right). 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.

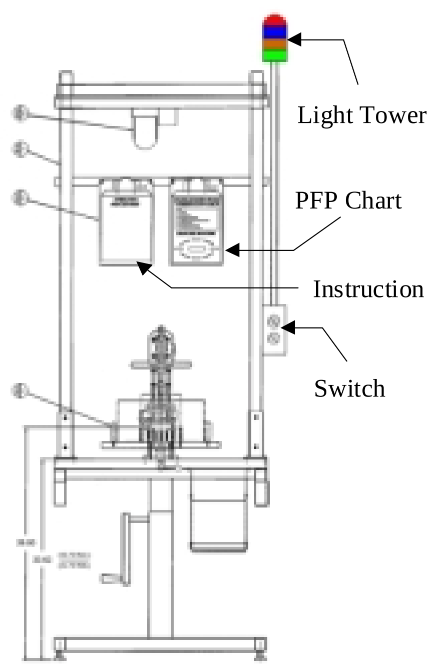
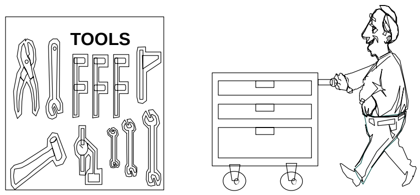


Figure 4

2.1.6. Workplace Organization



Good Bad

A place for tools, gages, etc., should be established for easy operator access. Searching through a drawer full of tools wastes time and reduces productivity.

Use an outline of each tool or gage to make it obvious when one is missing.

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 the operator 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 operators to pace their work throughout the cell, like the 24-second shot clock in the NBA. 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.

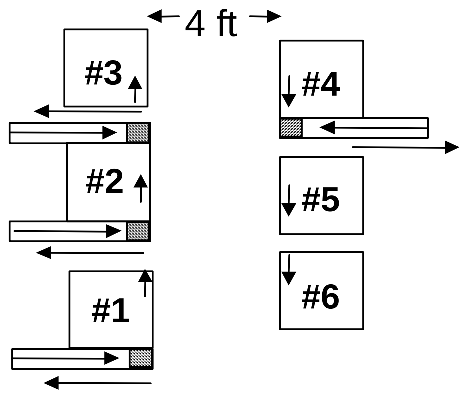
2.1.8. Distance Between Machines

Machines should be placed less than 12” apart or as close to each other as practical to minimize walk distances and the use of floor space. Over the course of an 8-hour shift, walking distance adds up as shown in Table 1 below.

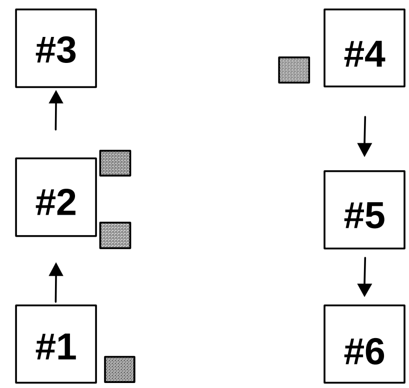
WALKING TIME TABLE			
Steps	**Feet**	**Seconds**	**Miles/8 HR Shift (@ 30 sec TAKT Time)**
1	2.5	.6	.43
2	5.0	1.2	.85
3	7.5	1.8	1.28
4	10.0	2.4	1.70
5	12.5	3.0	2.13
6	15.0	3.6	2.55
7	17.5	4.2	2.98
8	20.0	4.8	3.40
9	22.5	5.4	3.84

Table 1

Cell width should be a maximum of 4 feet as shown below.



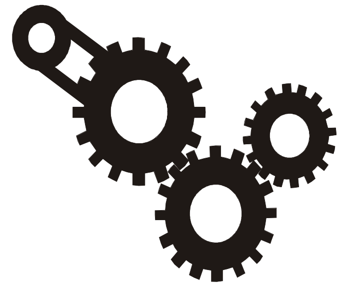
Good



Bad

2.2. Simplified

Moving material in one-piece flow in smaller customer focused modules gives us both a challenge and an opportunity. One-piece flow demands higher uptime to get the needed throughput. More and smaller modules lead to greater TAKT time and the opportunity to slow machines down. Simplified equipment reduces both investment and downtime. Simplified equipment may also increase the number of suppliers.



Our thought process needs 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. All complexity starts with air and power. Putting the complexity into the tooling, rather than the machine, can reduce cost and improve flexibility (e.g. drill, chamfer, and counterbore 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 (cams, pulleys, etc.) offering less downtime and easier maintenance and trouble shooting.

2.2.1. Proper Use of Automation

Understand what needs to be controlled and how best to use people for value added tasks and automation only where necessary. An example might be in a welding operation, where an operator may be capable of controlling the speed of the welder, but the control of the wire feed needs to be electronically monitored and controlled. To be less automated means to focus on automating the "right" things. Typically, when discussing "less automated", we are considering shifting from semi or full automation processes, where there is little or no human involvement other than filling parts containers, tool changes, changeovers, etc., to more manual work where the operator is more involved in loading, unloading, transferring, and visually inspecting parts. Minimizing the use of automation reduces capital.

2.2.1.1. Levels of Automation

Shigeo Shingo (one of the key architects of the Toyota Production System) in his book "A Study of the Toyota Production System" [6] wrote about the various steps in automating equipment. Below are the six steps or stages (modified slightly) of Automation Evolution:

Stage 1 - Manual load, manual process and manual unload. An example is the tightening of a fastener with a basic wrench.

Stage 2 - Manual load, automatic process and manual unload. The operator loads the part and initiates the cycle. The operator stays with the machine during the cycle. Upon completion, the operator unloads the part and monitors for defects.

Stage 3 - Manual load, automatic process and manual unload. During the process, the operator moves and runs other equipment. The operator loads the part and initiates cycle; the operator does not stay with the machine during the cycle. The equipment makes the operator aware of problems.

Stage 4 - Semi-automatic, manual load, automatic process and automatic unload. The equipment sends out a warning alarm when a defect is sensed.

Stage 5 - Pre-automation. Automatic load, automatic process and automatic unload. The equipment stops in the event of failure and the operator corrects the fault in station.

Stage 6 - Automation. Automation includes entire automatic processing, trouble detection, and correction.

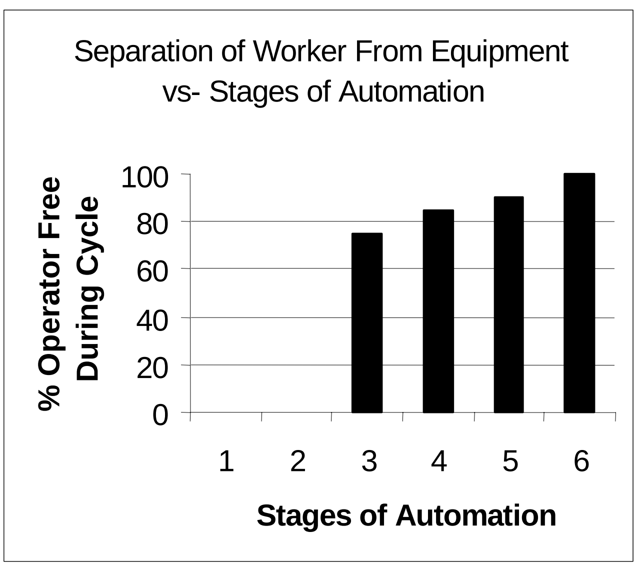


Figure 5

As we progress through the different stages of automation, notice how the operator is separated from the equipment to a larger and larger degree. The transition from Stage 2 to Stage 3 frees up an operator during a large percentage of the cycle. However, as you progress through to the other stages, your labor savings increase to a lesser degree. Figure 5 at left shows this relationship graphically.

Associated with moving to more automation is additional investment cost in equipment to: sense errors/defects, orient correctly, convey, engage or disengage automatically. Automation for these tasks typically adds little or no value and leads to more indirect support (Engineering, Maintenance and Training) and more potential downtime. Figure 6 shows this investment cost relationship graphically.

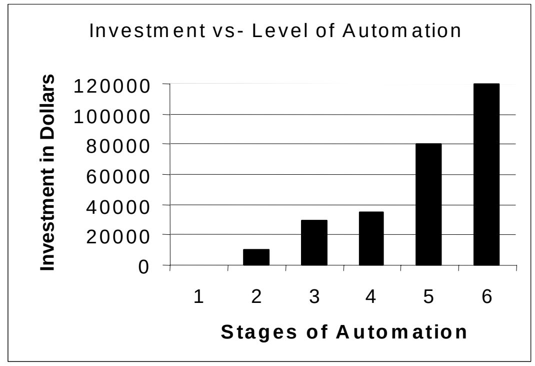


Figure 6

When justifying the cost of increased automation, look at what we are really saving by doing so. The additional cost to fully automate can be very significant compared to the small percentage of an operator's time (typically 10%) saved.

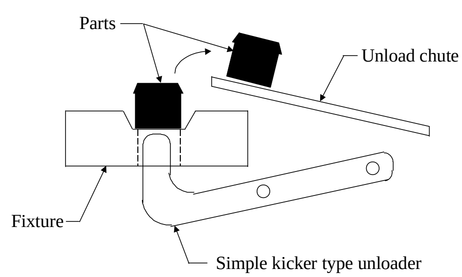
2.2.1.2. Manual Loading

Manually loading takes advantage of the human ability to coordinate eye/hand movement and tactile feel during part loading.

- Loading parts from part bins allows the operator to orient them at the same time. Auto loading requires that parts be oriented before loading.
- Eliminate all obstacles between part bins and machine nest.
- Chamfer nests to allow ease of placement of parts and reduce wear.

2.2.1.3. Manual Unload vs. Auto-Eject

Auto-eject is a machine feature that is beneficial when an operator is running multiple processes and leads to the elimination of a handling step. When parts are large and can't be picked up with one hand, the operator must put down the part they are attempting to load in the machine and remove the part from the fixture.



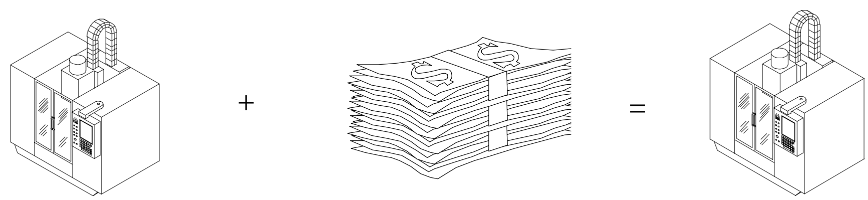
When designing a machine we should start with a concept of a simple auto-unload. Concern over part quality/potential damage sometimes adds to the cost and complexity of auto-eject and may make it undesirable.

- Design machines that include auto-eject of completed parts toward the operator side of the machine in the direction of part flow whenever possible.
- Auto-eject devices should maintain part orientation. This helps the operator when loading to the next machine or fixture.

2.2.2. Use “Off-the-Shelf” Machines

Purchasing “off-the-shelf” machines can save us time and money. When equipment suppliers build custom machines, delivery times are longer and costs are generally higher. All machines, even “off-the-shelf,” must meet all local and national standards i.e., (NFPA-79 and the Delphi addendum) and ANSI Standards.

Equipment and suppliers are often asked to “customize” machines to use a certain set of components, both mechanical and electrical. While this helps the manufacturing plants standardize and reduce the number of spare parts inventoried and reduce training requirements, it can add significantly to machine cost and delivery times.



Commercially Available

Built to Delphi Specifications

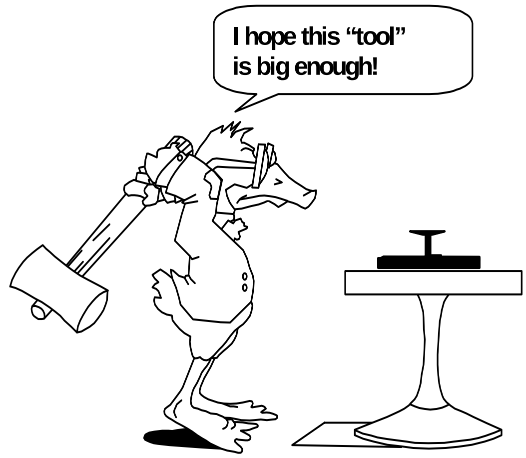
Continue to work with purchasing and machine suppliers to make the Delphi machine a shelf item. This implies we can commonize within Delphi from plant to plant, and division to division.

When “off-the shelf” is not possible, ask yourself:

- What extra are we paying for? (Why pay for 3 sec. cycle time when 20 sec. will do the job)
- Does it provide a strategic advantage?
- Will it conflict with standardization?
- Will it require additional training and/or service personnel?

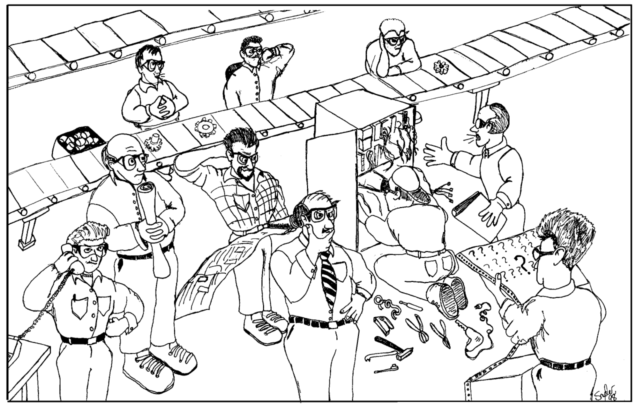
2.2.3. Right Size Electrical/Mechanical Components

Design to meet the requirements (no-overkill). Don’t pay extra for what we don’t need. It drives equipment size larger and cost higher. For example, purchasing a larger size control enclosure to have “spare space” may make it more difficult to bring material in from behind the machine because now the control enclosure is in the way.



- Use 110vac service power whenever possible, this will help reduce electrical enclosure size by reducing the space needed for a 440vac 3 phase disconnect.
- Use low end (small) controllers when possible.
- Use remote/block I/O where practical.
- Wire directly into I/O modules to eliminate redundant terminal strip.
- Use IEC components properly sized to help reduce control enclosure/operator panel size.
- Keep the spare control enclosure space less than 10%.
- Limit position sensors to only what is needed.
- Consider higher hydraulic pressure to help reduce the size of mechanical components.
- Use air rather than hydraulics if it will do the job.
- Use an arbor press instead of air if it will work.
- Use a 2 hp motor instead of a 5 hp motor if that is all that is needed.

2.2.4. Minimize Use Of Conveyance



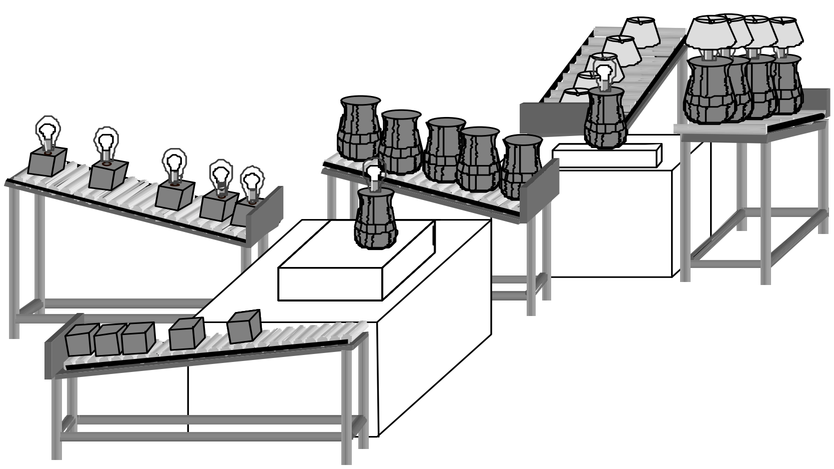
Conveyors must be used carefully or they can be a source of much waste. Our first choice for moving parts between operations within a cell is manually by the operator. In cases where parts are heavy and operators need an assist device, non-powered conveyors should be considered to avoid cost, complexity and potential downtime. There are cases, such as vehicle assembly, where motor driven conveyors must be used.

- Use standard modular conveyors when they are required. End flanges that can accept sprockets or be bolted to the next section add flexibility in conveyor length and layout.

- If powered conveyors are used, consider variable speed to adjust for demand (TAKT Time) changes. This allows a way to pace the operation.

- Powered conveyors can be continuous motion. This allows the operator to continue working on a part and not have to hurry when a part is about to "index" out of the workstation.

- Non-powered conveyors can use gravity to assist in part movement as shown in the figure below.



2.2.5. Eliminate Waste in Equipment

In the Manufacturing System Design methodology, we learned to break down the operator tasks and determine where operators are adding value using the operator balance chart. In the machine balance chart, shown in Figure 7 below, machine cycle time, as indicated in the green checkered highlighted area of each stacked bar, is usually assumed to be adding value. In this example, the second operation (leak test) is a very expensive machine that runs much faster than required and then waits. The Leak Test adds no value. Where possible, eliminate such testing and use process monitoring and control to produce good parts and verify with audits. If it must remain, can we use more cycle time and reduce investment? In the fifth operation (press/weld), the machine cannot produce a part fast enough to meet TAKT time and may have to be duplicated, or split into two machines, with shorter cycle times.

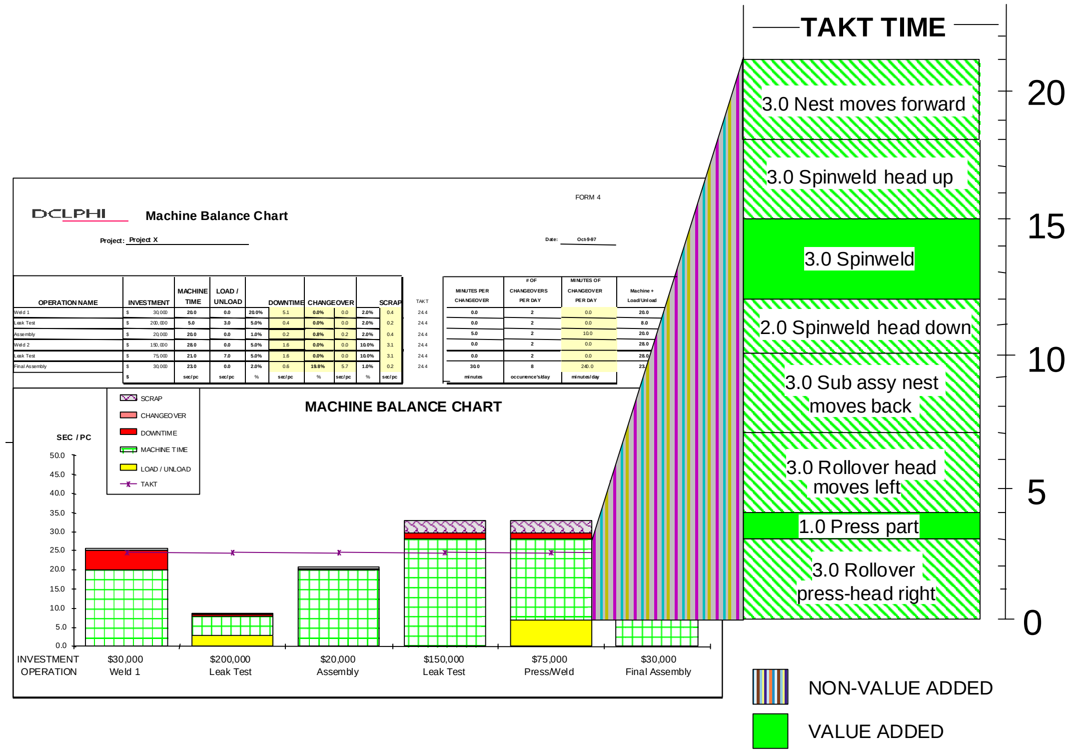


Figure 7

Further analysis of the cycle time in the fifth operation, as shown in the expanded "machine time" stacked bar, shows waste in the machine cycle. During only 4.0 seconds of the 21 second machine cycle is the machine adding value. This value is indicated by the solid green areas in the expanded stacked bar. If the part was loaded at the point of operation and the press and spinweld operations could take place in one position, then 9 seconds of time could be eliminated. By "eliminating" and "combining" these steps, we have reduced machine cost and complexity.

Each non-value added machine motion adds machine costs, maintenance cost and increases downtime. Investment is higher, controls cost/complexity are greater. Examples 1 and 2 in section 3 show further analysis of machine cycle time for value added content.

- Loading at the point of operation must be considered if it can be done safely.
- When loading can’t be at the point of operation; raised barrier guards eliminate pinch points. Eliminate variation due to moving critical fixturing on slides and shuttles.
- Small 2-position rotary dials can act as an auto-eject mechanism while separating the operator from hazard areas. Use of this added mechanism must be balanced against the benefits of auto-eject.

2.2.6. Minimize Machined Surfaces

Design equipment to minimize machined surfaces. Don’t pay for something you don’t need. Why machine the whole surface of a mounting plate when only a small area of it needs to be machined? Eliminate all unnecessary surface area.

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.

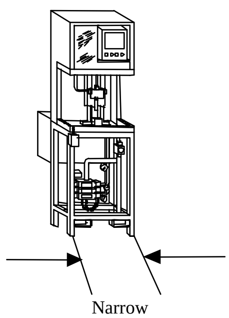
2.3. Supports One-Piece Flow

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

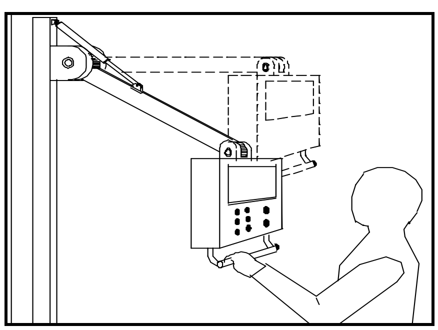
To support one-piece flow, machines must be close together so that operator walk distances are minimized. If walk distances are large, operators will be tempted to batch parts and store extra inventory between machines.

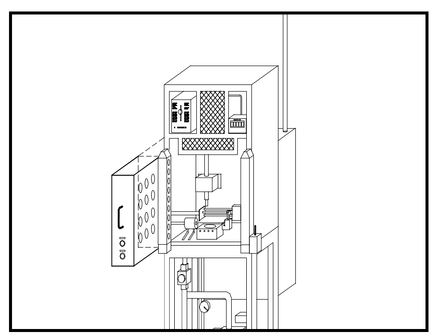
2.3.1. Narrow Effective Width Machines



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.



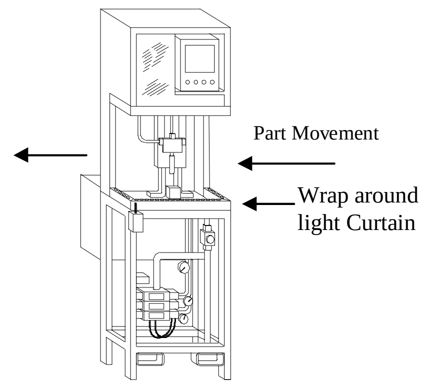


Service areas should be at the back or front of the machine with no side access required. Side access requirements force machines further apart increasing effective width.

Some machine suppliers are beginning to make trapezoidal shaped machines to reduce effective width at the operator interface. This is effective at the curve in a U-cell.

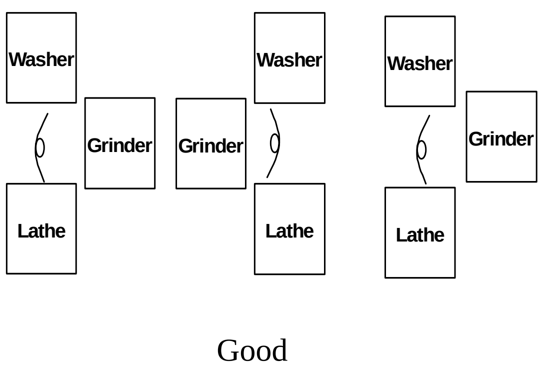
2.3.2. Machine is Open on the Sides

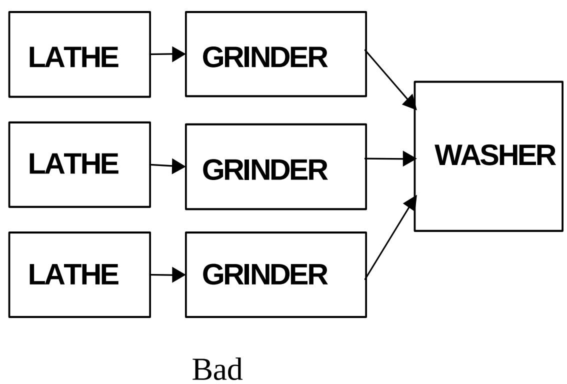
The use of C-Frames eliminates wasted motion of moving parts around posts and reduces possible part damage due to added part handling.



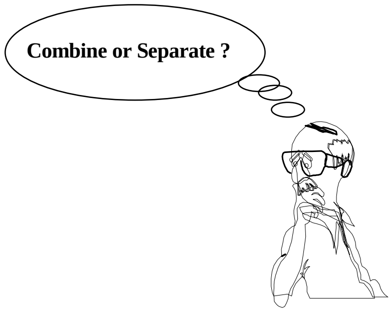
2.3.3. Avoid Large Batch Type Off-Line Equipment

Try to utilize multiple smaller machines incorporated within the cell (e.g. painting, washing, heat treating etc.) when possible. This eliminates waste in excess inventory, travel distance and facilitates one-piece/smaller lot flow. Large batch processing equipment, often referred to as monuments, are typically inflexible, lengthy to change over and difficult, if not impossible, to move or relocate. Furthermore, material does not flow well through this equipment.





2.3.4. Review Multiple Operation Equipment



Typically, simple workstations are often linked into large dial machines or transfer lines. The linking of these "stations" with automatic material handling is often done to save material handling labor and to meet short cycle times. As we move to smaller manufacturing cells with greater TAKT times and as we prepare machine and operator balance charts, we must review the value-added workstations to see if they should be combined or kept separate to better utilize the operator. Linking these stations together would not be an issue if uptime and change over time were 95% and 10 minutes, respectively.

Example 5 in Section 3 shows where a two (2) operation workstation was split into 2 separate workstations.

Example 10 in Section 3 illustrates a case where five (5) complex machines (each having one value added station) linked by conveyors were combined into one machine with multiple stations. To accomplish this and still meet our reliability goals, one operation was eliminated and others were simplified.

2.3.5. Manual Backup

The viewpoint of production and the machine's uptime must be considered when selecting and designing equipment. When an automated system or an automated load and unload device is used, design the machine or system so it can be operated manually.

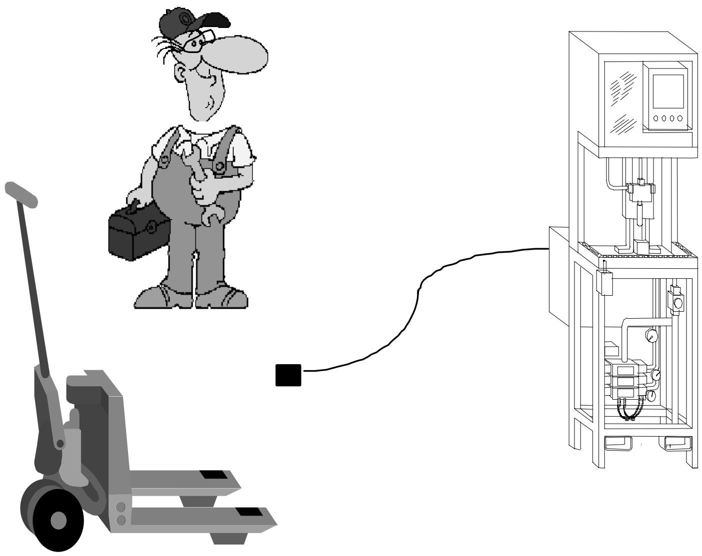
Determine during the design phase how the automated portion can safely be by-passed, if necessary, and what additional tools are required to perform the operation manually. Make sure that the work place is designed to include the manual back up tools. It is also important to document the manual method with set-up instructions, process checks, preventative maintenance plans, and operator instructions. The backup method must be maintained and checked periodically in order to ensure that it will function if required.

- Back up robotic welding equipment with semi automated MIG welders that trained operators within the cell can use.

- Sonic weld horns from an automated sonic weld station can be rotated out of position and the same nest can be used to hold the parts as the operator uses a hand sonic weld gun to perform the weld.

- Hang manual screw/rivet guns on an automatic station so operators can manually drive screws/rivets, if the automatic rivet station experiences problems.

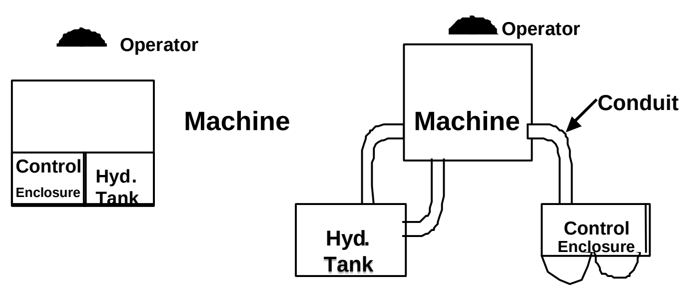
2.4. Portable and Flexible



Equipment must be as portable and flexible as possible. A goal in flexibility is to be "in synch" with the customer, 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. All equipment will be moved at least once in its lifetime (when relocated from the machine builder to the production area). 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 (quicker to market).

2.4.1. Design Equipment to be Self Contained

Self contained equipment has control enclosures, hydraulics, cooling systems, chip collection, leveling, vibration isolation, etc. all on one base. Self contained equipment is easier to move because no rewiring or piping is required.



Good Bad

A next best alternative to having the control enclosure on the same base is temporary control enclosure mounting points for moving. See Figure 8.

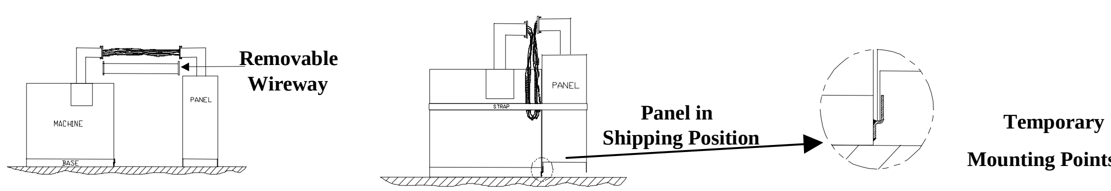
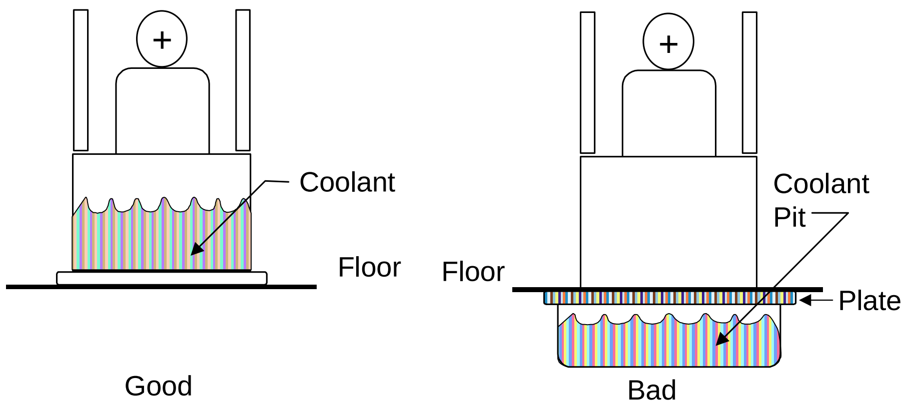


Figure 8

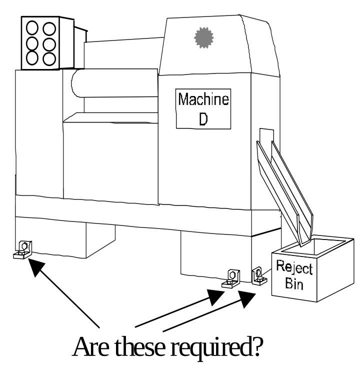
2.4.2. Provide for Flat floor Mounting

Equipment should not require any floor preparation such as pits, foundations or catch basins. Relocating equipment that is part of the building is difficult and expensive, if not virtually impossible. The elimination of pits has an added environmental advantage. Pits can fill with hazardous material and leak through the slab into the ground. Since these leaks are not visible, they are often not repaired immediately.



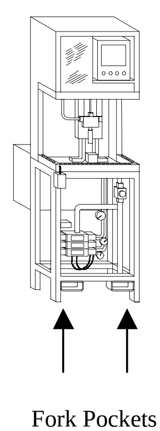
2.4.3. Avoid Fastening to Floors

To reduce relocation time, do not fasten equipment to floors unless it is necessary. (e.g. tight tolerance, vibration, narrow footprint, top heavy conditions, etc.). Lockable wheels or Teflon footpads may be evaluated to make it easier to reconfigure machines that are not lagged down.



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.

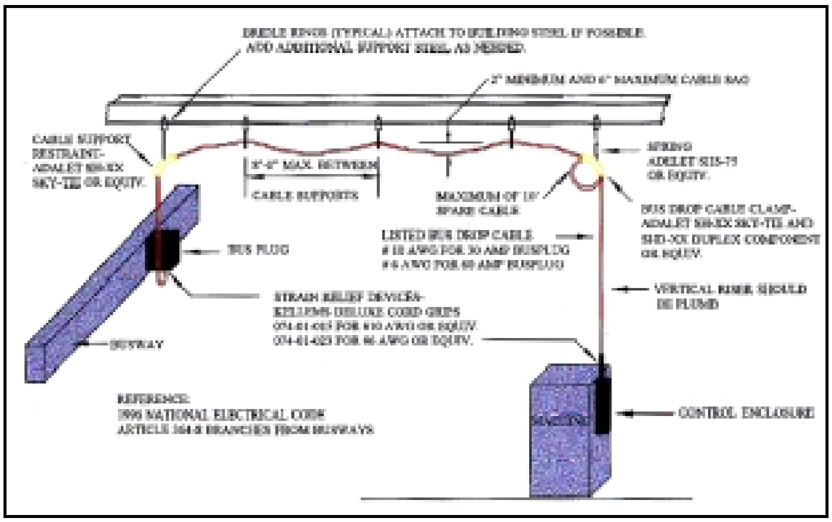


2.4.5. Use Flexible Drops and Quick Disconnect Utility and Ventilation Connections

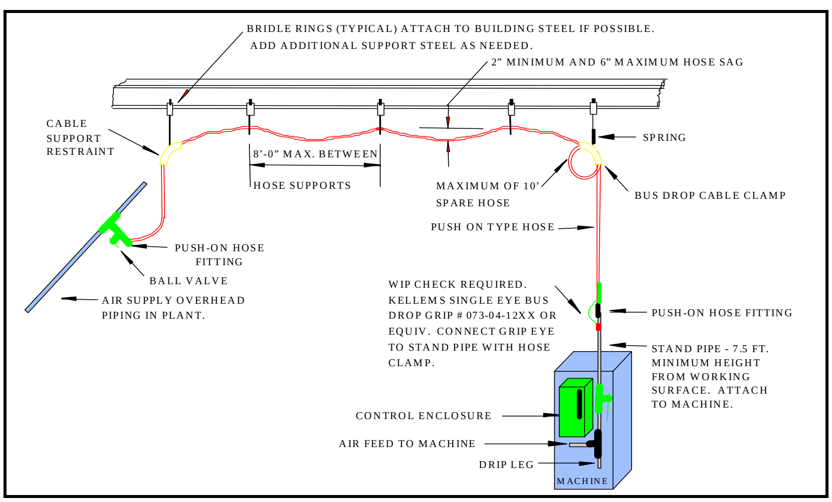
Keep utilities and ventilation above ground using flexible drops and quick disconnects where possible. Avoid steam and natural gas. Flexible electrical connections will be done only as allowed by the National Electrical Code (NEC).

- Strain relief devices should be used to tie hose and cable to machine to prevent accidental strain on them.
- Enough extra line for movement of equipment realignment of service without disconnecting shall be provided. (Note: National Electric Code requires vertical flexible drops).
- Only qualified personnel install or move equipment and all power is shut off to avoid equipment damage and/or personal injury.
- Refer to local equipment controls group for further details and examples of Flexible Utility connections.

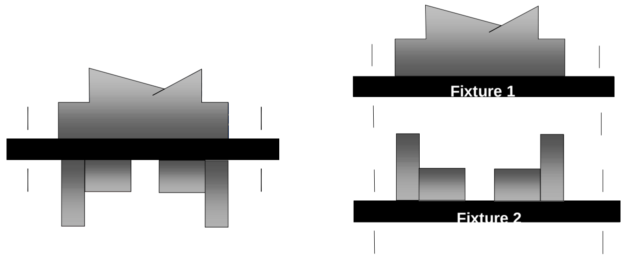
Flexible Electric Drop



Flexible Air Drop



2.4.6. Support Quick Changeover



Good Bad

For batch processes such as stamping or molding, machines need to be capable of changing over rapidly from part-to-part in order to meet dynamic daily customer demands.

Changeovers steps are sometimes called elements. Internal elements are those steps performed while the machine is down. External elements are those steps performed before stopping the machine and after starting it back up. Rapid changeover is accomplished by transferring all internal setup elements possible to external setup elements and by standardization and elimination of waste. Quick change is extremely important to system flow in batch processes in order to fill downstream pull signals while holding low inventory levels. Changeover participants must have responsible and standardized tasks. Standardized tasks support continuous improvement.

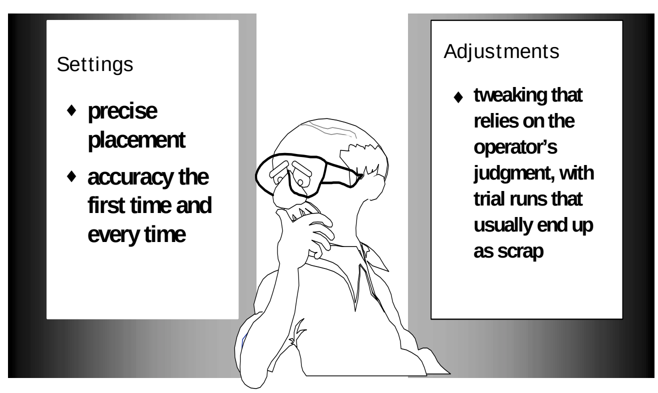
The cell or process must have the ability to run every part every day and quick changeovers help to make this realistic. Fixtures must have clearly indicated and positively located setup positions with a goal of changing equipment over without the use of hand tools. This is possible through workplace organization and the use of clamps, toggles, lock pins, etc. The goal is model changeover $\leq$ TAKT time.

Use rollover or interchangeable fixturing.

Other ideas from the Quality Network QN-777[7] include: Use fewer bolts. Utilize cams, toggle clamps, wing nuts or locating guides.

2.4.7. Avoid Adjustments

Design controls, tooling and fixturing with no adjustments or "fine-tuning" required. Create pre-determined locations or settings with fixed positions. Don't require operator judgment and trial runs to see if parts are good. This saves setup time (increasing machine operating time), reduces or eliminates buffers of inventory (cost) and eliminates scrap (cost).



Typically, few machine builders know how often or how many different tools or dies a manufacturer plans to change, so little effort is put into simplifying the process.

Shigeo Shingo in his discussion of Single Minute Exchange of Dies (SMED)[8] provides the following examples of ways to avoid adjustments:

- **Least common multiple system -** If a process requires adjustment with a limit switch at any one of several settings, place a switch at each position connected to its own power switch. Then, when a different setting is required, only that switch is activated.
- **Drilling -** When drilling to multiple depths for different part sizes requires different stop settings, provide pre-set stops for each depth.
- **Machining -** When multiple jigs are required to position parts for different tooling, rather than adjusting each time one is needed, put all jigs on a common rotating fixture with an insert pin or locking device to locate the required position.
- **Fabricating -** When fabricating different sized parts is based on the setting of a stopper positioned by an adjustable guide screw, replace it with a fixed stopper and multiple positioning jigs.

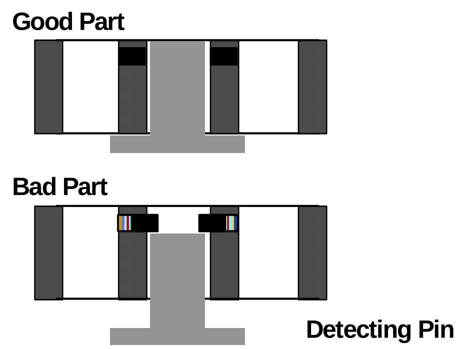
2.4.8. Design for Flexibility to Future Changes

Product designs change. Schedules change. Similar products are often introduced so now, instead of one part, there is a "family of parts" to run. The equipment must be designed to anticipate all of these situations. Some of the ways to achieve this were discussed earlier in this section, such as quick change over and eliminating adjustments. Another example, for a part that has two or more distinct components or operations in the "family", would be to add extra machines that can be quickly moved in and out of the cell during change over. They could also be left in place, assuming this does not disrupt the flow in the cell, and turned on or off as required. The goal of flexibility is to have level operating costs with any size family of parts and at any volume level.

2.5. 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. Try to detect a defect before adding additional value that will be wasted (see Reference (9)).

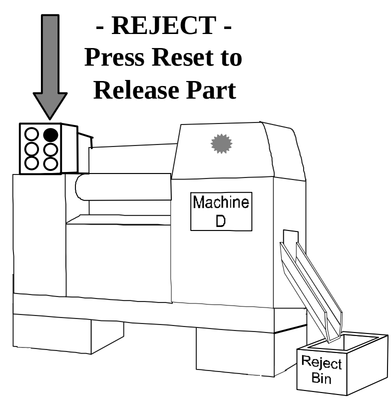
2.5.1. Provide Simplified, Built-In Error Proofing



Error proofing methods must be utilized to eliminate potential sources of failure found in Failure Mode Effects Analysis (FMEA). Error preventive fixturing and color coding (not always as effective) are preferred over functional testing.

Design fixtures and machines to detect abnormalities (such as incorrect orientation or mixed parts) and to stop and signal automatically whenever they occur. Part presentation could also be utilized to assist in error proofing. The system should be designed to assure bad parts do not flow down the good part path. This will prevent the waste that would result downstream by working on the defective part.

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

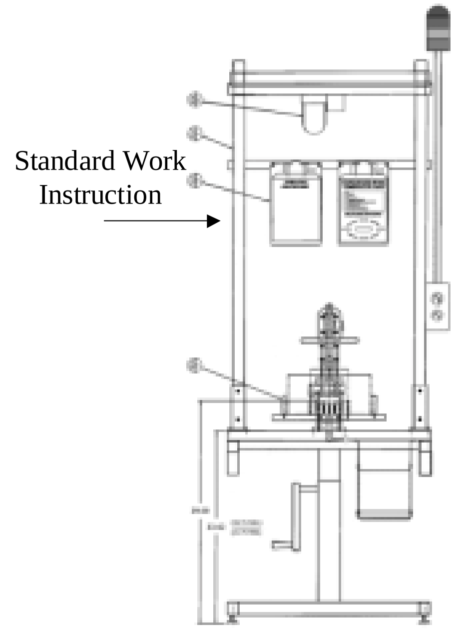


Design equipment to detect errors and insure that machine rejected parts are contained properly and removed from the process. The equipment must alert the operator when this occurs and require a “non-normal” activity such as releasing the rejected part.

Sometimes a chute with a switch is used to ensure the rejected part is not passed forward.

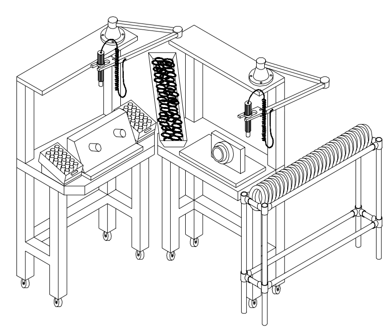
2.5.3. Support Standardized Work

The equipment design should make it difficult to deviate from standardized work. For example, when operations require parts to be picked from a container, don't allow space for parts to be stockpiled, mixed with other parts during changeover, and/or dropped or damaged.



Have machine design include a location to post standardized work.

Avoid areas which might accumulate "extra" inventory or other materials contributing waste and poor workplace organization. Figure on right shows no room for defective parts, pop cans, or other waste.



2.5.4. Boundary Samples

Boundary Samples must be provided with machines. "Known Bad Master" parts must be provided to allow the operator to verify that all test or verification systems are functioning properly at an interval specified by the Manufacturing/Quality Organization.

"Known Bad Master" parts should be readily identifiable (i.e. RED in color or identified in some manner such that they will not be inadvertently shipped to the customer).

"Known Bad Master" parts should have a permanent storage location along with instruction for the proper sequence of operations to perform verification steps.

2.6. Reliable and Maintainable

In order to support one-piece flow, equipment must be reliable and maintainable. Slower, simpler machines designed to module TAKT times should be more reliable and therefore have less down time. Should the equipment fail; however, it must be designed such that recovery from failure can be rapidly accomplished. Equipment must be designed for quick diagnosis and fast repair. (See Delphi Planned Maintenance System and Implementation Guide[10]).

2.6.1. Equipment Designed for Planned Maintenance

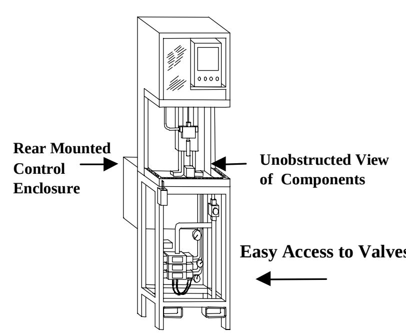
MACHINE P.M. SCHEDULE	1	2	3	4	5	6	7	8
CHANGE AIR FILTER		✓						
CHANGE LIGHT BULBS					✓			
CHANGE BELT			✓					
CHANGE COOLANT					✓			
CHANGE OIL FILTER					✓			
CLEAN OUT SUMP		✓		✓				
ADJUST TENSION				✓				
TIGHTEN GIBBS		✓						
INSPECT WAYS								
MOTOR SIGNATURE			✓					

The goal of Planned Maintenance is to ensure equipment and tools are ready and able to run when needed, which in turn lowers plant costs. It includes scheduled and unscheduled maintenance programs with strategies for responding to machinery and equipment failures. Design the machine so scheduled maintenance can be performed at a time specifically planned to minimize interruptions in manufacturing and assembly (e.g. during lunches or breaks). The planned maintenance should cover daily, weekly, monthly, quarterly, and annual tasks as required.

Design equipment with the owner/operator concept in mind. Owner/operator is a concept whereby the operator of the machine assumes the role of owner with responsibility for the condition of the equipment. At a minimum, equipment should be designed so that operators can identify problems such as; noises, vibrations, oil leaks, and low fluid levels and notify maintenance prior to negative impact on uptime.

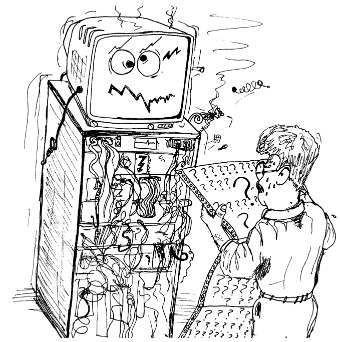
2.6.2. Equipment Designed for Accessibility

Design the machine for easy access to control enclosures, hydraulic units, and pneumatic valves by providing:



- Easily removable guarding.
- Place all serviceable components behind machine for unobstructed entry <u>after</u> installation.
- Clearance for tools.
- Unobstructed view of components.

2.6.3. Equipment Designed for Maintenance Diagnostics



If diagnostic devices are required, they should be kept simple to reduce complexity and controls requirements, be built into the equipment, and include:

- Visible and/or audible indication of maintenance required
- Self diagnosis and correction instructions
- Identification of faults to component/module level
- Capability for storing performance data
- Output format compatible with “off-the-shelf” software

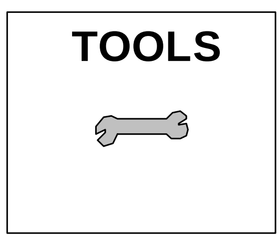
Plexiglas cover or housings on components permit quick visual check without disassembly.

Use LED’s whenever possible to help keep the diagnostic display small and simplistic.

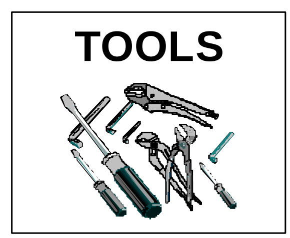
When more complex diagnostics is required, utilize human machine interface for diagnostics.

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 includes the use of commonized fasteners and tools. This will also greatly reduce spare parts inventories and associated carrying costs.



Good



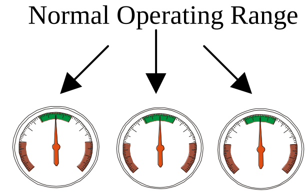
Bad

Pay attention to final destination of machine and what components are available there.

If “off-the-shelf” equipment conflicts with plant standards, can the machine supplier provide service support and commonly replaced parts inventory as part of a PM contract?

2.6.5. Information Management

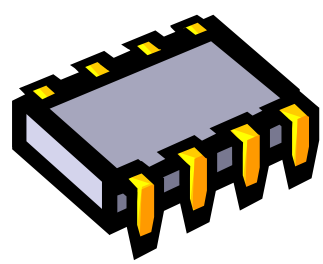
A key to equipment maintainability is the availability and understanding of the necessary information. Once a master set of operating parameters is established, one needs to be quickly informed of an abnormal condition and be able to return it to normal. This can be facilitated through:



- Match Marking fasteners.
- Marking directions of rotation and flow.
- Contents of cabinets & control enclosures labeled.
- Dirty filter indication and replacement part number labeled.
- Put a Machine Manual on the machine.
- Identify mechanical and electrical home position for diagnostics 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. gear box, circuit board, drive unit). Although typically thought of in terms of electrical components, this can be applied to mechanical elements as well. Fixing circuit boards, gearboxes, etc. often requires specialized skills, tools, and training. 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. Also, use standard vs. specialized electrical connectors. Be careful not to "overkill" the use of quick disconnection and waste money.

3. Equipment Design Examples

The examples of equipment provided in this section reflect the areas discussed in Section 2. Some examples show violation of the principals outlined in the guidelines and are marked as a (-). Other examples show areas of conformance (+) with the guidelines. A (?) indicates questions that cannot be answered with the information available.

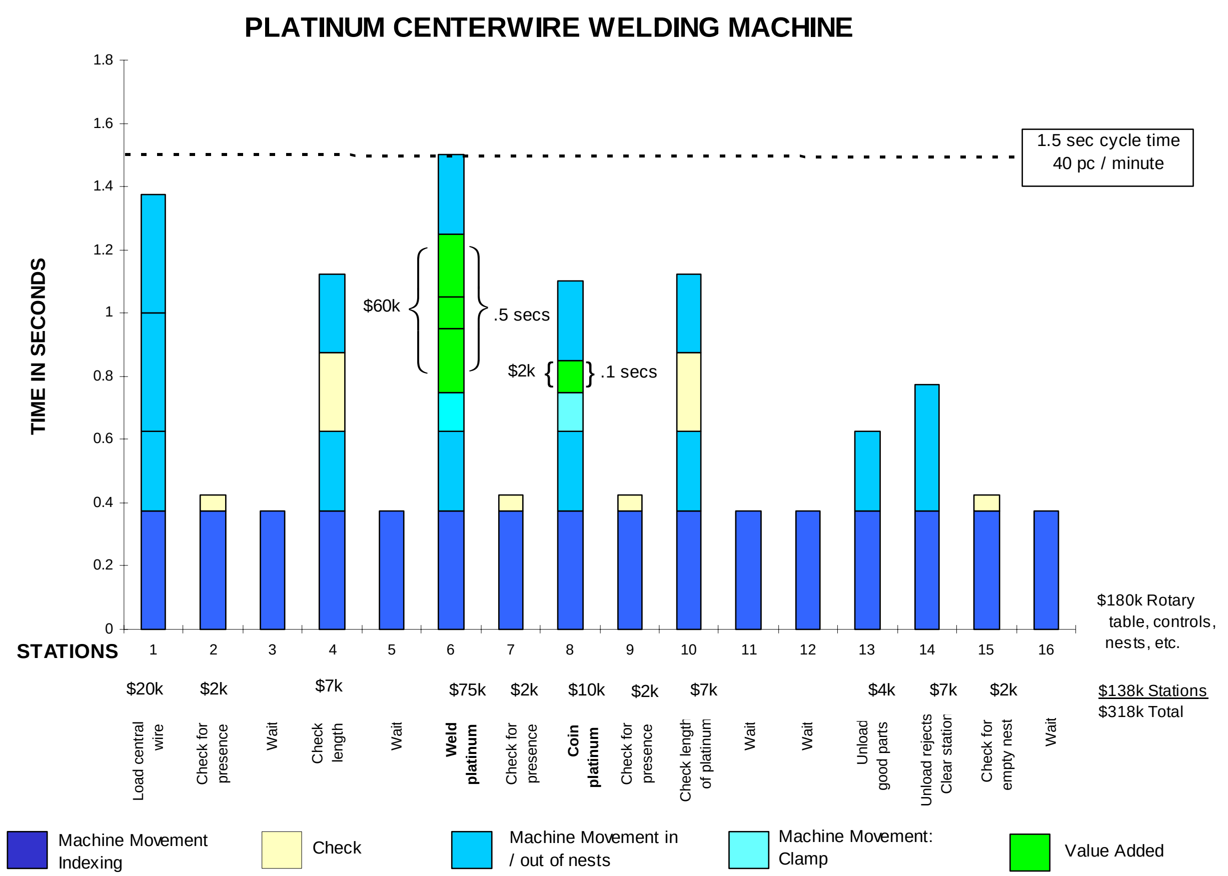
Examples

Example 1:	Value Added Analysis Of A 16 Station Rotary Table Welding Machine
Example 2:	Value Added Analysis Of A 2 Operation Press/Weld Machine
Example 3:	Analysis Of A Small Lot Size Wash Operation.
Example 4:	Analysis Of A Flexible Weld Station
Example 5:	Analysis Of A Work Station Replaced By 2 Separate Stations.
Example 6:	Analysis Of An Assembly Machine.
Example 7:	Analysis Of A Mold Machine
Example 8:	Analysis Of A Stake And Grease Machine.
Example 9:	Analysis Of A Bearing Press Machine.
Example 10A:	Analysis Of 5 Separate Final Assembly Operations (Before).
Example 10B:	Analysis Of Combined Final Assembly Operations (After).

Example 1: Value Added Analysis Of 16 A Station Rotary Table Welding Machine

Description:

Platinum Centerwire welding machine in Spark Plugs at Delphi-E. This machine is a bowl fed rotary table that runs at 40 parts/minute. The operator stocks and tends 2 machines. Parts are loaded to the nest at Station 1. Parts are lifted from the nest in Stations 4, 6, 8, 10 for processing and then dropped back into the nest. Only stations 6 and 8 add value to the product.



VALUE ADDED ANALYSIS:

$$\frac{.6 \text{ sec}}{1.5 \text{ sec x } 13 \text{ stations}} = 3\ \%\ \text{of time in machine is value added}$$

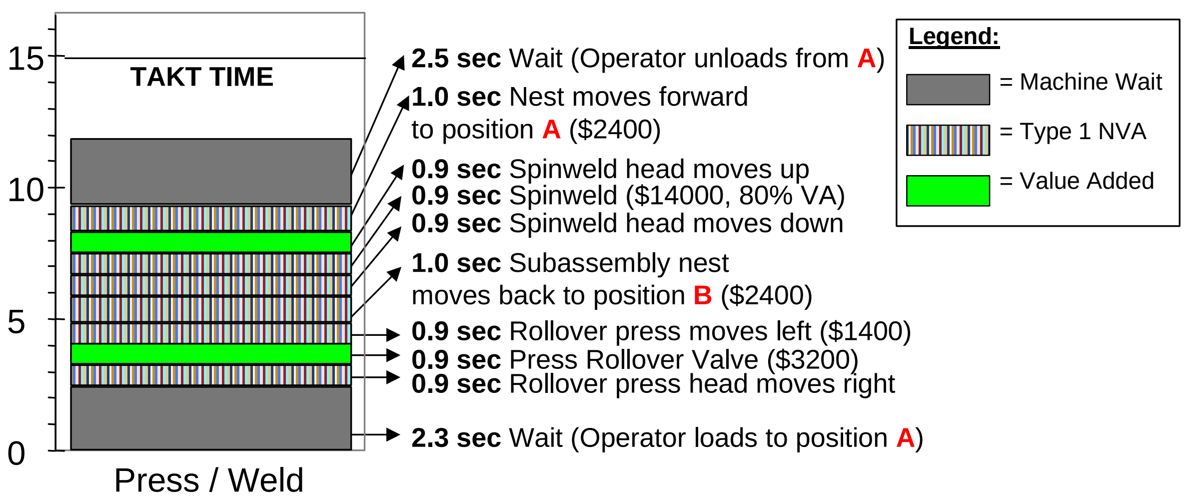
$$\frac{\$62\text{ k}}{\$318\text{ k}} = 19.5\ \%\ \text{of machine cost is value added}$$

Example 2: Value Added Analysis Of A 2 Operation Press/Weld Machine

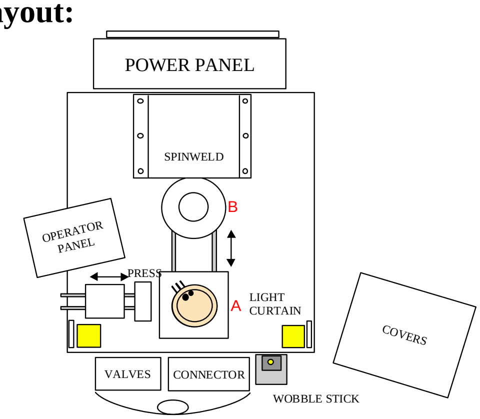
Description:

Press/Spin Weld operation in Modular Fuel Assembly at Delphi-E. The operator pre-assembles parts while the machine is running, unloads the complete part, loads the nest with next assembly, and initiates the cycle. The operator stays at this station. The breakdown of the machine cycle is shown below. The value-added portion of the machine cycle is shown in green.

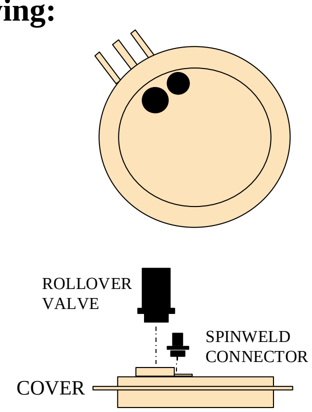
Press/Weld Machine Cycle Analysis



Layout:



Part Drawing:



OTHER COSTS:

CONTROLS	$6000	(20%VA)
LIGHT CURTAIN	$3000	(0% VA)
BASE	$2000	(100% VA)

VALUE ADDED ANALYSIS:

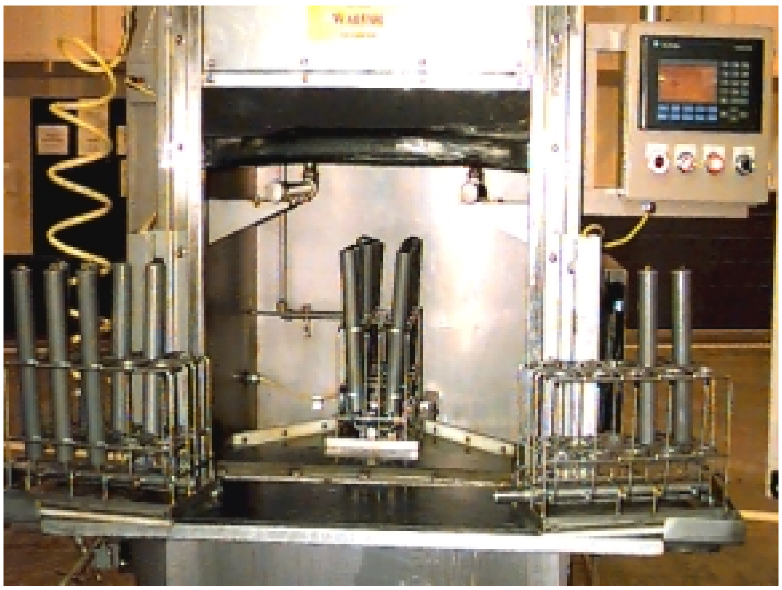
(.9 SEC + .9 SEC)/12.2 x100 = 15% of time is VA

$17,600 / $35,800 x100 = 49% of cost is VA

Example 3: Analysis Of A Small Lot Size Wash Operation

Description:

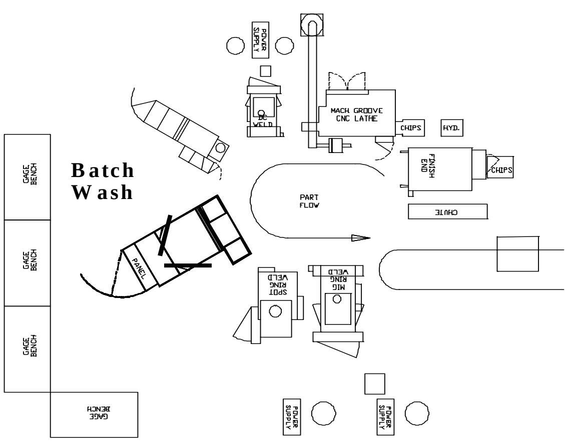
Washer used in manufacturing of Monotube Dampers. Part of the Monotube Damper Tube Cell at Delphi-C in Dayton. In this operation the operator walks between 8 machines. The TAKT Time is 35 sec. The wash time is 240 sec. The washer cleans both the OD and the ID of the tubing. This is a modified version of a washer that is used in the baking industry to clean bread pans. Operator manually slides basket, containing 10 tubes, into the washer and initiates cycle. Door closes and parts are washed and dried. Wash cycle will not start if basket is not properly located (error proofing).



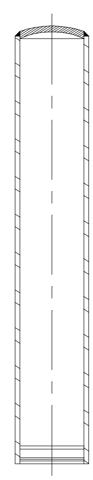
- + Manual load & unload
- + 10 pc flow
- + High uptime
- + Replaced 3 washers
- + Self contained
- + Flex drops

Washer Station – Monotube Damper Tube Cell

Layout:



Part Drawing:



Example 4: Analysis Of A Flexible Weld Station

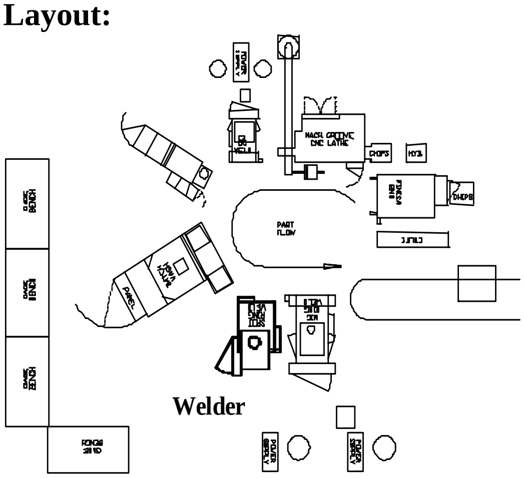
Description:

Welder used in manufacturing of Monotube Dampers. Part of the Monotube Damper Tube Cell at Delphi-C in Dayton. In this operation the operator removes the previous part, places the tube and ring in the fixture and initiates cycle while walking to the next machine. The TAKT time is 35 sec. The cycle time is 5 sec. The welder can weld either the ring (as shown) or a bracket. The tube rotates into the welder. The weld occurs. The tube ring assembly then rotates back to the load/unload position.

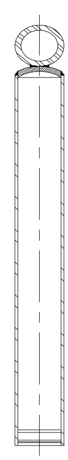
+ Flex drop/quick connect
+ Easy initiated cycle start (whisker switch in direction travel)
- Operator panel adds to effective width
+ Mounting Ring is loaded at point of operation
- Tube is loaded onto a sleeve that rotates automatically to point of operation
- TAKT Time >> cycle time

Weld Station – Monotube Damper Tube Cell

Layout:



Part Drawing:



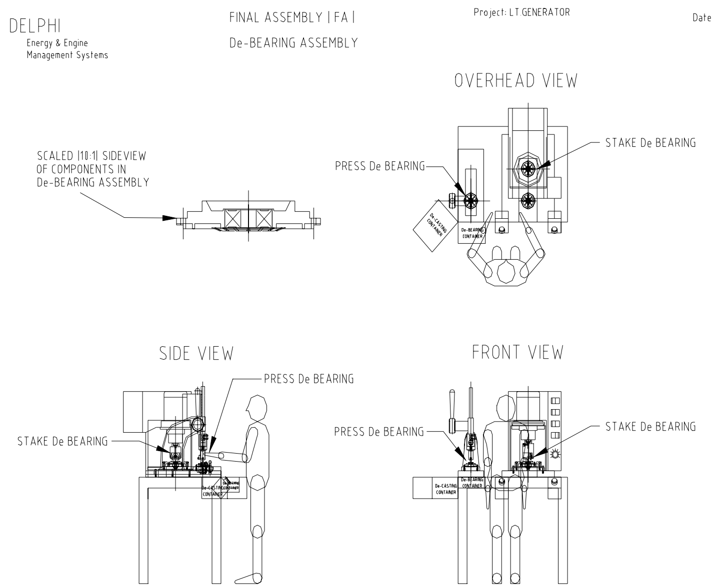
Example 4 "-" changed to a "+" Mounting Ring is loaded at point of operation. 2nd Print

Example 5: Analysis Of A Work Station Replaced By 2 Separate Stations.

Description:

Liquid Cooled Generator Assembly Cell. Original workplace has 2 fixtures on single base. Stake Station has shuttle to move part under stake head. Parts are placed at the workstation as shown in the original layout. Revised concept allows for material delivery from behind the workplace, out of the operator walk path.

Original Workplace Concept



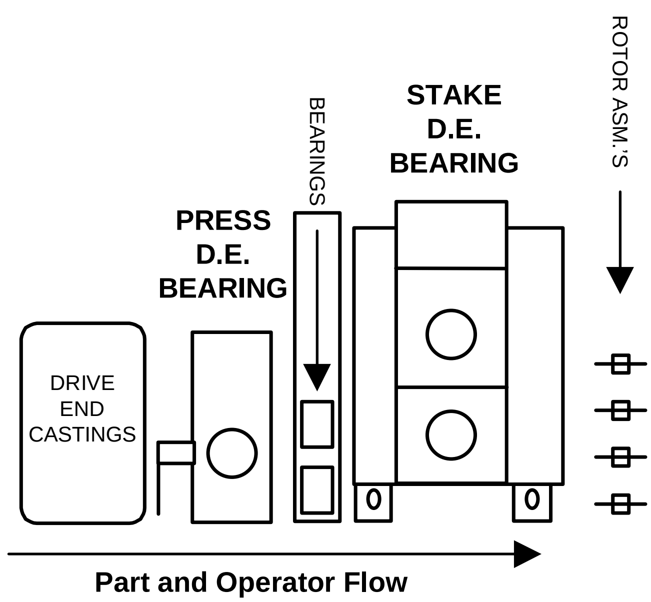
- Added motion of shuttle in stake station

+ Separate stations allow for stand alone part racks moving parts from behind

- Two hand cycle initiation

+ Control enclosure in rear

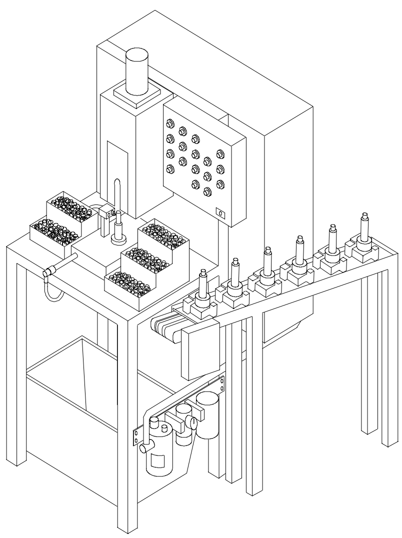
Revised Workplace/Layout Concept



Example 6: Analysis Of An Assembly Machine

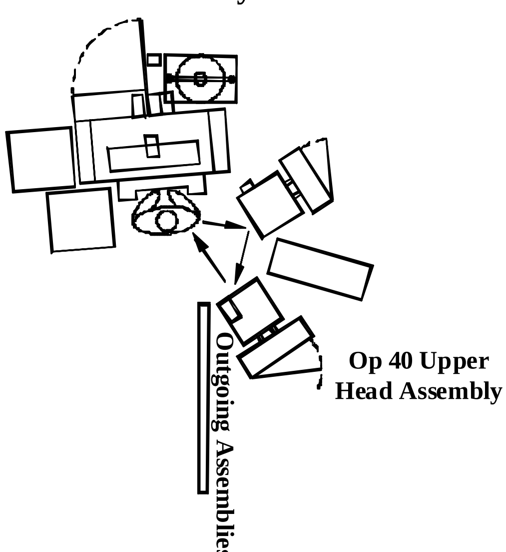
Description:

Steering Upper Head assembly machine at Delphi-S, Plant 6 in Saginaw. In this operation, the operator walks between three machines. The TAKT time is 59.2 sec. In this workstation, the operator places the yoke assembly from the previous operation on the fixture, places the housing over the yoke assembly, and places the inner race, inner race seat, upper bearing spring, spring retainer, and retaining ring. The operator then places a thimble over the yoke assembly. The press is cycle started and the operator waits 3 seconds, unloads, and places the part to the conveyor which feeds the next operation.

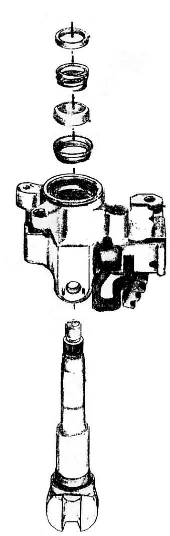


- \- Operator panel adds to width
- \+ Narrow base
- \+ Load at point of operation
- \- Wide control enclosure
- \- Position of valves on side. May be OK in this application if part rack is moveable
- \- Small parts containers can't be supplied from behind due to control enclosure size/placement
- \- Machine base wider just to hold small parts

Layout:



Part Drawing:

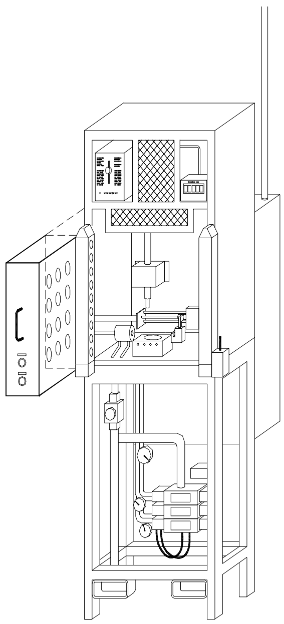


Removed Operator panel adds to width; duplicate line; 2nd Print

Example 7: Analysis Of A Mold Machine

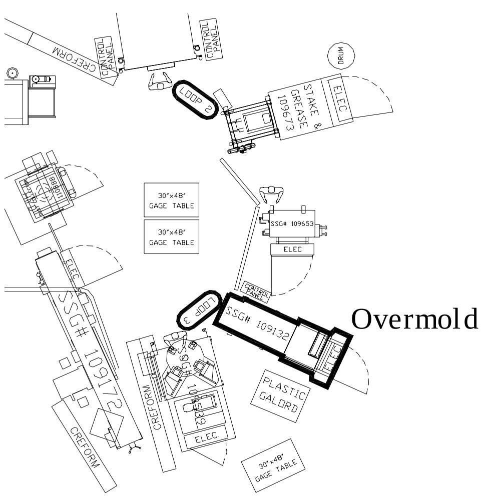
Description:

Overmold machine molds plastic onto solid shaft and yoke assembly. Part of the Intermediate Shaft Cell at Delphi-S, Plant 7 in Saginaw. In this operation, the operator walks between two machines. The TAKT time is 15.0 sec. At this workstation, the operator unloads the previous part, loads the part, initiates cycle by a wobble stick, and moves to the next machine. The machine cycle is 8.0 seconds including load time.



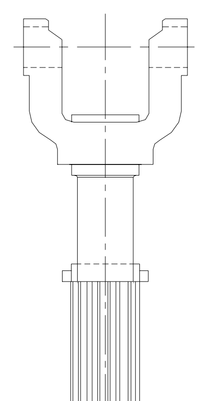
+ Cycle initiated by wobble stick
+ Load at point of operation
± Slide out operator panel adds some width but is better than turning the operator panel 90°
+ Narrow effective width (narrow end faces operator)
+ Control enclosure located at back

Layout:



Part Drawing:

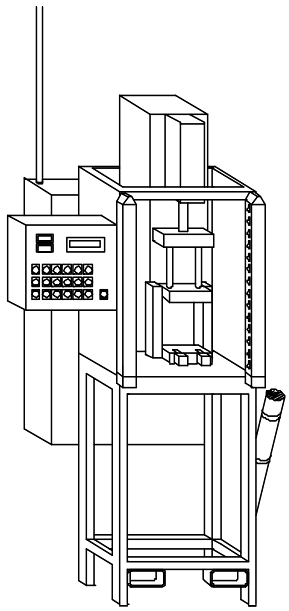
Plastic To Completely Cover Splines Of Steel 10 Tooth Solid Shaft.



Example 8: Analysis Of A Stake And Grease Machine

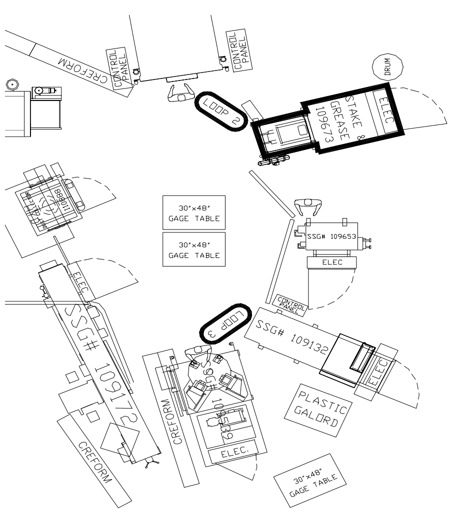
Description:

Intermediate Shaft Stake torsion assembly and Grease operation. Part of intermediate shaft cell at Delphi-S, Plant 7 in Saginaw. In this operation the operator walks between two machines. At this workstation, the operator unloads the previous part, loads the next part, initiates the cycle via the light curtain, and move to the next machine. The TAKT time is 15.0. The machine cycle is 3.0 seconds including load time.

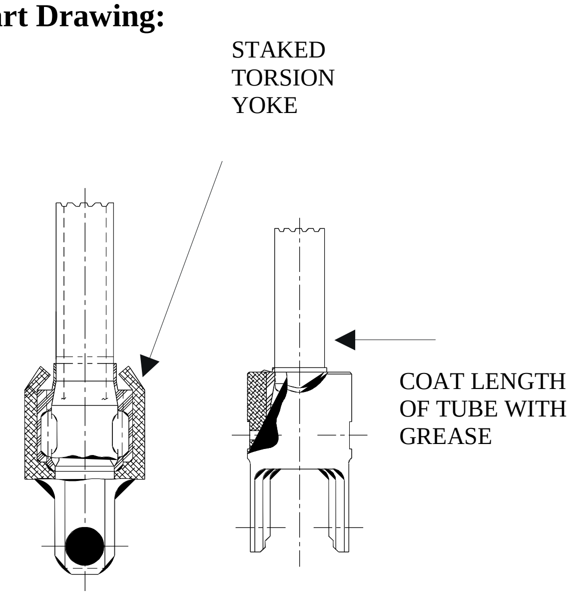


+ Light curtain initiates cycle
+ Load at point of operation
- Operator panel adds to effective width
+ Control enclosure in rear
- Control enclosure adds to width
+ Right amount of information for operator/maintenance on operator panel, specific faults listed
+ Disposal chute is interlocked
- Hard wired
+ Self contained machine
- Not C-Frame

Layout:



Part Drawing:

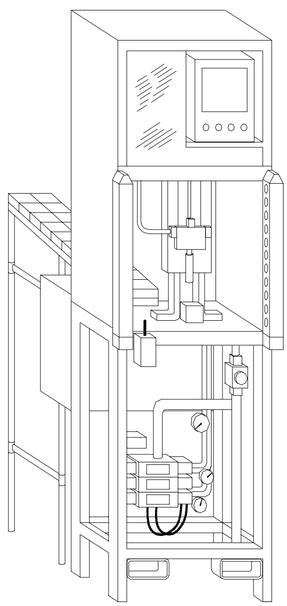


Example 8 - Removed side tray from machine. 2nd Print

Example 9: Analysis Of A Bearing Press Machine

Description:

Press Bearing onto Drive Shaft. Part of Pump Assembly Cell at Delphi-S, Plant 3 in Saginaw. In this operation, the operator walks between 10 machines. The TAKT time is 78 sec. The machine cycle time is 5.9 sec. The operator manual loads a drive shaft, and bearing picks up a completed assembly from the previous cycle and hits the whisker switch. The part is automatically unloaded. The bearing is fed to the operator from the back of the machine. The operator is protected by a light screen.



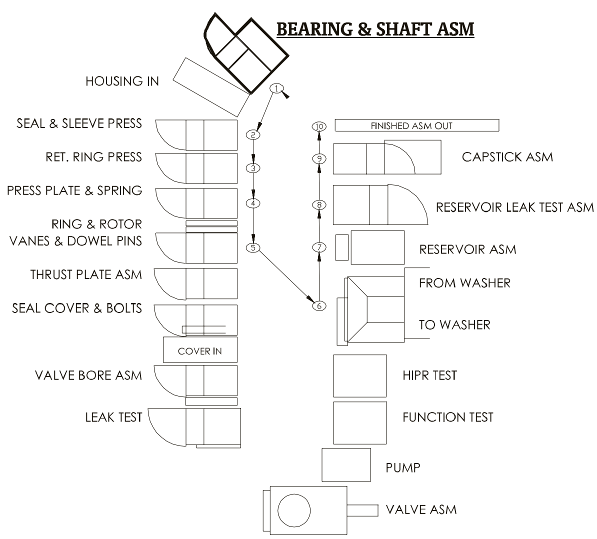
+ Narrow effective width (small operator panel within width)
+ Flex drops for both electric and air

The part is automatically unloaded

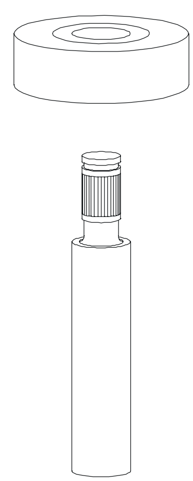
+ The bearing is fed to the operator from the back of the machine to the point of use
+ Control enclosure in rear
+ Self contained
+ Fork pockets
+ No side access required

- TAKT Time >> cycle time

Layout:



Part Drawing:

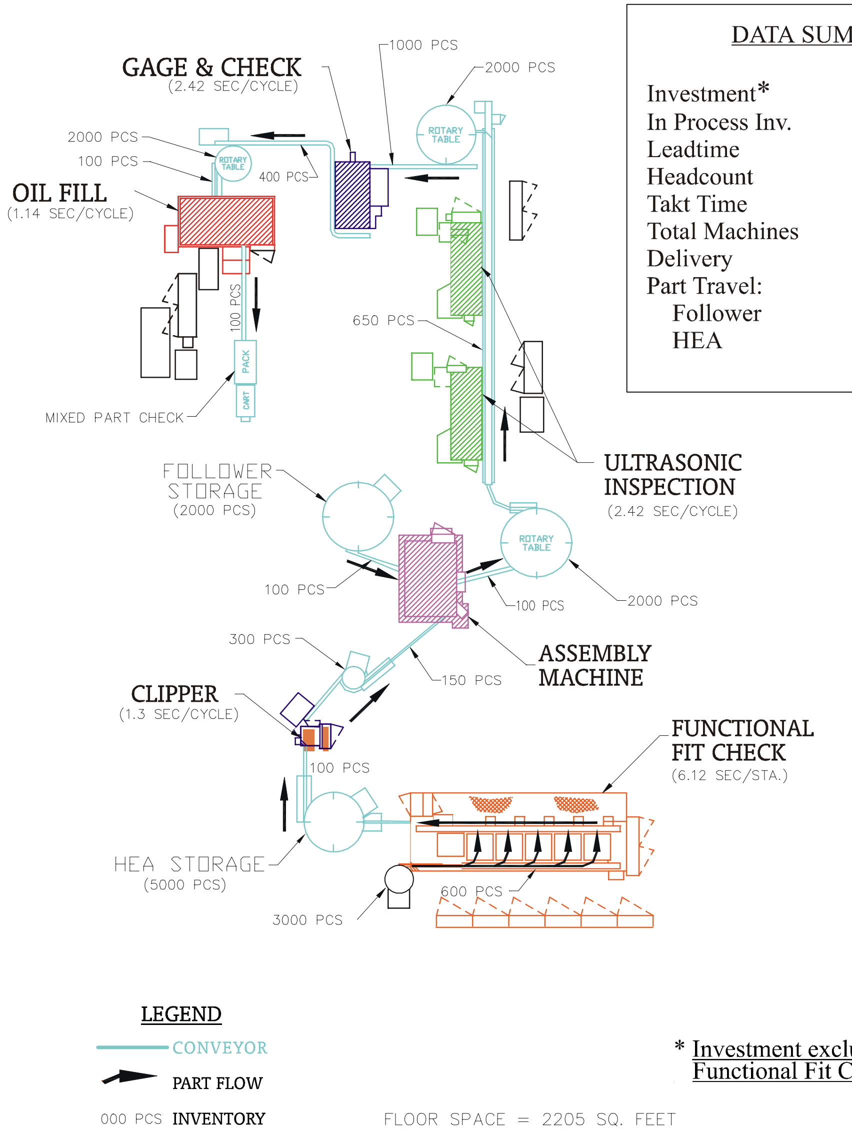


Example 10.A: Analysis Of 5 Separate Final Assembly Operations (Before)

Description:

Original design of Hydraulic Element Assembly/ Follower (HEA) Cell. Part of the Hydraulic Valve Lifter process at Delphi-E in Grand Rapids. TAKT time is 1.97 sec. Machine cycle times are shown below. After the clipper operation, the cell contained five (5) separate machines for final assembly, ultrasonic inspection (2), gage checks, and oil fill. The parts flow between machines was performed by utilizing tracking and rotary storage tables. Inherent in this process was a majority of the test and inspection being done on a finished assembly.

ORIGINAL LAYOUT



DATA SUMMARY

Investment*	$ 3.0 Mil
In Process Inv.	19,600 pcs
Leadtime	163 min
Headcount	3/shift
Takt Time	1.97 sec/pc
Total Machines	7
Delivery	24 mo.
Part Travel:	
Follower	140 ft.
HEA	70 ft.

* Investment excludes the Functional Fit Check machine.

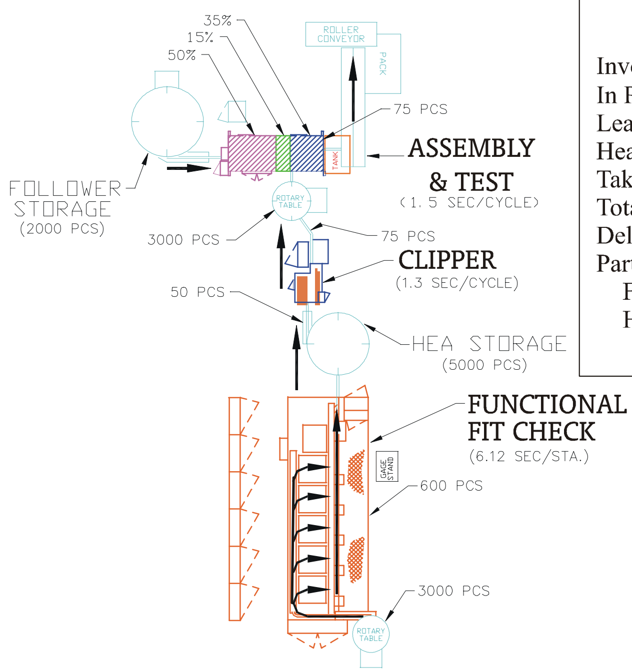
Example 10.B: Analysis Of Combined Final Assembly Operations (After)

Description:

The new design for the Hydraulic Element Assembly (HEA) Follower cell replaced five (5) separate machines with one (1) machine that combined component gaging, final assembly, assembly inspection, and eliminates oil fill as a separate operation by doing all of these functions while the assembly is submerged in oil.

Components gaging and assembly of the Hydraulic Element Assembly Follower is 50% of the new machines functionality, with ultrasonic inspection at 15% and final assembly gaging being the remaining 35%. The combining of the machines, and revolution in parts conveyance and storage systems has reduced operator requirements by 50% floor space utilization by 60%, and investment by 88%.

CURRENT LAYOUT



DATA SUMMARY

Investment*	$ 350 K
In Process Inv.	13,800 pcs
Leadtime	98 min
Headcount	1.5/shift
Takt Time	1.97 sec/pc
Total Machines	3
Delivery	6 mo.
Part Travel:	
Follower	20 ft.
HEA	35 ft.

* Investment excludes the Functional Fit Check machine.

LEGEND

CONVEYOR

PART FLOW

000 PCS INVENTORY

FLOOR SPACE = 882 SQ. FEET

Appendix A - Lean Equipment Checklist

1. System Design
2. Supports The Operator
3. Simplified
4. Supports One Piece Flow
5. Portable/Flexible
6. Zero Defect Quality
7. Reliable and Maintainable

LEAN EQUIPMENT CHECKLIST

1. SYSTEM DESIGN

DESCRIPTION	REFERENCE	ANSWERS			COMMENTS
1.3 Has a Lean Manufacturing Workshop been performed on this process? Date completed? ___________________	May be called Manufacturing System Design Workshop. Frequent use of full scale workstation models.	Yes		No	
1.3.2 What is the TAKT Time (seconds)?	Scheduled Time (Available Time) / Customer Requirements (LCR)	>30	15-30	<15	
1.3.4 What is your machine cycle time vs. TAKT time?		80% - 85%	85% - 95% 70% - 80%	> 95% <70%	
1.3.5 What kind of plant layout will you have for your product?		Product Focused		Process Focused	
1.3.5 How are raw materials and other parts brought into the cell?		One Piece Flow	Small Lot (Pushcart)	Batch (Fork trucks)	
1.3.5 Does the layout/machine design allow for empty containers and finished parts to be removed from the cell?		Yes		No	
1.3.6 Who is responsible for audit type gaging and testing, not included in operators standardized work?___________________		Team Leader	Advisor	Operator	
1.3.7 Have bottleneck operations within a cell been identified?		Yes		No	
1.3.7 Will buffers be used at these bottleneck operations?		Yes		No	
1.3.7 Within a cell, what is the maximum number of machines between buffers?		7-8		>10 < 5	
1.3.7 Has the size and necessity of buffers between cells been determined?		Yes		No	
1.4 Has the size and necessity of all buffers been validated by a simulation model?		Yes		No	
1.4 Was an approved simulation package used? Specify ____________________		Yes		No	
Does your equipment/tooling conform to the Bill of Process (Manufacturing Footprint)?	Delphi Automotive Systems -- *Bill of Process Reference Guide*	Yes		No	
Has a DFM (Product) Workshop been done?	Delphi DFM COE; GM KnowledgeCenter	Yes		No	

NOTE: This Checklist Section, System Design, duplicates the one found in MSD Methodology. Skip to the Next Section if this was completed as part of the MSD Activity.

Changed Heading from "Lean System Checklist" to "Lean Equipment Checklist" 2nd Print

LEAN EQUIPMENT CHECKLIST

2.1 SUPPORTS THE OPERATOR

DESCRIPTION	REFERENCE	ANSWERS			COMMENTS
2.1.1 SAFETY & ERGONOMICS					
2.1.1.1 Are lockouts/disconnects in one location?		Yes		No	
2.1.1.2 Has guarding been considered in the design of the machine?		Yes		No	
2.1.1.3 Have safety and ergonomic guidelines been reviewed and met?		Yes		No	
2.1.1.3 How are ergonomic issues addressed? (i.e. repetitive motion)		Standardized Work	Job Rotation	Automation Complexity	
2.1.1.3 Is there a common work (part) height between stations?		Yes		No	
2.1.2 How is the cycle started?		Automatic (Light Screen)	Whisker Switch / Touch Sensor	Push / Palm Button	
2.1.3 Have efforts been made to reduce machine noise?		Yes		No	
2.1.4 Are storage racks and material handling devices reusable, reconfigurable, or flexible? (ex. Creform)		Yes		No	
2.1.4 Are storage racks/containers sized to optimize inventory at machine/cell and to provide FIFO?		Yes		No	
2.1.5 Are buffer sizes visually displayed?		Yes		No	

LEAN EQUIPMENT CHECKLIST

2.1 SUPPORTS THE OPERATOR

Continued

DESCRIPTION	REFERENCE	ANSWERS			COMMENTS
2.1.5 VISUAL AND AUDIO CONTROLS					
2.1.5 Has an Andon system been utilized or incorporated in machine design or cell design to display machine/system status?		Yes		No	
2.1.5 Are cycle counters or an Andon board being utilized to alert operator to make scheduled tool changes (equipment stops if this is not done)?		Yes		No	
2.1.5 Are cycle counters or an Andon board being utilized to alert operator to make scheduled gage checks?		Yes		No	
2.1.5 Are ranges for gages and fluid levels clearly identified?		Yes		No	
2.1.6 Has a place for tools, gages, etc. been established and is it easily accessible to operator?		Yes		No	
2.1.7 What is the pacing mechanism in this cell?	If a conveyor or other automation is required, use it to start and pace the cell.	Machine Controlled	Visual or Audio Alert (Timer)	Operator Controlled	
2.1.8 What is the distance between machines in a cell?		< 12 in.	12-24 in.	>24 in.	

Added 2.1 Supports the Operator – Continued; 2nd Print

LEAN EQUIPMENT CHECKLIST

2.2 SIMPLFIED

DESCRIPTION	REFERENCE	ANSWERS			COMMENTS
2.2.1 PROPER USE OF AUTOMATION					
2.2.1.2 How are parts loaded in the machine(s)?		Manual	Low Cost Automation	Automatic	
2.2.1.3 How are parts unloaded from the machine(s)?	Use simple automation to remove the part from the load fixture so it is empty for the next part.	Low Cost Automation	Automatic	Manual	
2.2.1.3 When parts are unloaded from the machine, are they oriented for the next operation?		Yes		No	
2.2.2 Is this equipment "off-the shelf"?		Yes	Modification Required	No	
2.2.2 If modifications are required to the "off-the-shelf" equipment, how much additional cost has been added?		0-15%	15-30%	>30%	
2.2.2 If special built, is it a proprietary design that gives us a strategic advantage?		Yes		No	
2.2.3 Are electrical/mechanical components sized only to meet requirements?		Yes		No	
2.2.3 Is 110 VAC source power being utilized whenever possible?		Yes		No	
2.2.4 Has gravity been considered as a potential transfer mechanism?		Yes		No	
2.2.5 What percentage of the equipment cycle time is value added?	(value added time / total time) x 100	> 50%	30 - 50%	<30%	
2.2.5 What percentage of the total equipment cost is value added?	(value added cost / total cost) x 100	> 50%	30 - 50 %	< 30%	
2.2.5 Where are parts loaded into the machine?		Point of Operation		On To Shuttle	
2.2.6 Have steps been taken to reduce the machined surfaces on the equipment?	DFM-MTD – GM Knowledge Center	Yes		No	
Has a DFM - Machine & Tool Design (DFM-MTD) workshop been completed?	Delphi DFM COE; GM KnowledgeCenter	Yes		No	
What is the equipment/system projected Uptime?	(Actual Units / Planned Units) x 100 Where Planned Units =Sch. Run Time / Takt Time	90-100%	80-90%	<80%	
How is material moved within the cell?		By Hand	Manual Conveyor	Powered Conveyor	

LEAN EQUIPMENT CHECKLIST

2.3 SUPPORTS ONE-PIECE FLOW

DESCRIPTION	REFERENCE	ANSWERS			COMMENTS
2.3.1 What is the width of your machine?	12 inch minimum. Design to minimize operator walking.	Equal to part size. (Smallest Dimension)	2X Part Size (Smallest Dimension)	3X Part Size (Smallest Dimension)	
2.3.1 Is the operator control panel positioned in the front of the machine and not interfering with the path of the operator?	Minimize walk time and footprint.	Yes		No	
2.3.2 Is the machine open on the sides? (Including guarding.)		C-Frame		4 Post	
2.3.3 How is material brought into the cell from machine to machine?		One Piece Flow	Small Lot (Pushcart)	Batch (Fork trucks)	
2.3.3 Have batch type machines been replaced by multiple smaller machine and incorporated into a cell? (ex: paint systems, washers, platers)		Yes		No	
2.3.4 Have smaller machines been utilized to replace a multiple spindle machine?		Yes		No	
2.3.5 Can the system be run manually if the automation goes down?		Yes		No	
What is the lot size being processed?		1 pc.	Smallest Lot Container	Batch	

LEAN EQUIPMENT CHECKLIST

2.4 PORTABLE/FLEXIBLE

DESCRIPTION	REFERENCE	ANSWERS			COMMENTS
2.4 How long does it take to move the equipment, good part to good part?		0-4 hrs.	4-8 hrs.	>8 hrs.	
2.4.1 Is machine self contained? (control panels, hydraulics, coolant systems, chip systems, leveling method, vibration isolators, etc.)	Integral frame with all auxiliaries attached.	Yes		No	
2.4.2 Is this a "flat floor" installation?	No pits!	Yes		No	
2.4.3 Can the machine be installed without fastening to the floor?		Yes		No	
2.4.4 Are fork pockets and/or casters included in equipment?		Yes		No	
2.4.5 Are utilities and ventilation systems connected with flexible drops and quick disconnects?	Delphi Controls COE	Yes		No	
2.4.6 Have rollover or interchangeable fixtures been incorporated in the design?		Yes		No	
2.4.6 How long does it take to changeover? (Good part to good part.)		<10 min.	10-15 min.	>15 min	
2.4.7 Have adjustments been eliminated for set-ups and changeovers?		Yes		No	
2.4.8 Is the machine design flexible enough to accommodate potential product design changes or new products?		Yes		No	

LEAN EQUIPMENT CHECKLIST

2.5 ZERO DEFECT QUALITY

DESCRIPTION	REFERENCE	ANSWERS			COMMENTS
2.5.1 Does machine include error proofing to resolve items identified in PFMEA (including mixed and mislabeled stock)?		Yes		No	
2.5.2 How does machine or system handle rejected parts?		Part Held / Detection System	Part Held / No Detection System	Part Not Held / No Detection System	
2.5.2 Are reject parts identified at manual stations?		Parts are Identified, Discharged & Contained		No Containment System	
2.5.3 Does the machine design support a standardized work sequence?		Yes		No	
2.5.4 Have boundary samples been provided with the machine ?		Yes		No	

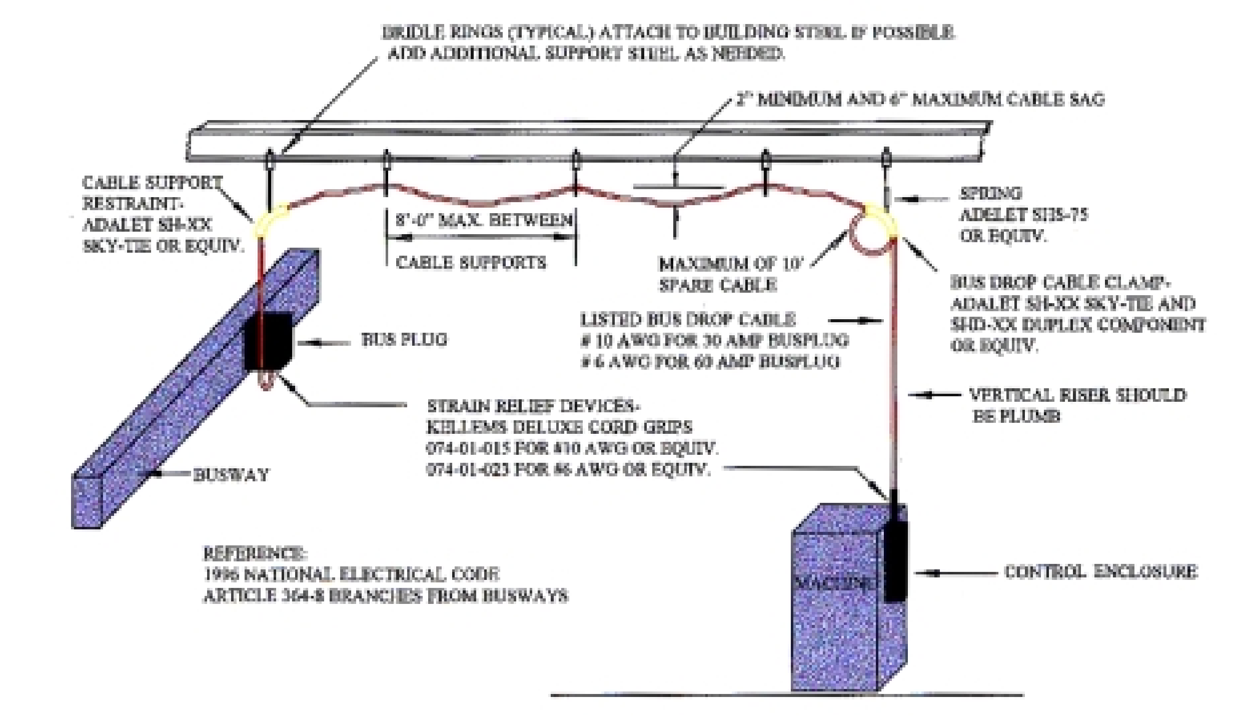
LEAN EQUIPMENT CHECKLIST

2.6 RELIABLE & MAINTAINABLE

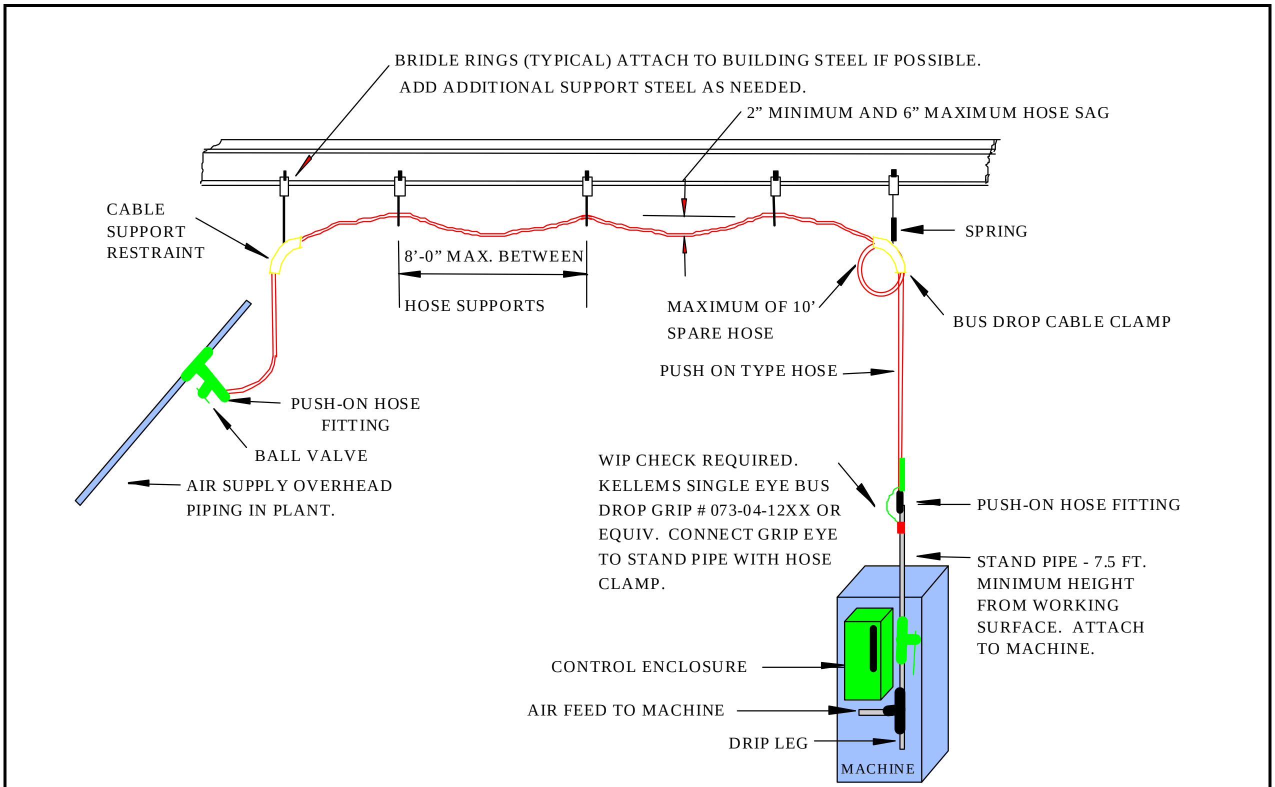
DESCRIPTION	REFERENCE	ANSWERS			COMMENTS
2.6.1 Has a PM Program been identified and initial spare parts been identified? (Standard format required.)		Yes		No	
2.6.1 Has a Total Productive Maintenance (TPM) Program been identified?		Yes		No	
2.6.1 Has the machine been designed to allow the operator to perform routine maintenance? (Including tool changes.)		Yes		No	
2.6.1 Has the machine been designed to allow the routine maintenance to be done in the following time frames?	Use scheduled downtime (lunch, breaks, etc) for maintenance activities.	0-10 min	10-30 min	>30 min.	
2.6.2 How long does it take to remove and replace barrier guards?		0-30 sec	30-60 sec	>60 sec	
2.6.2 Are all pneumatics, hydraulics, and control panels accessible from back of machine?		Yes		No	
2.6.3 Has the machine been designed with simple diagnostics?		Yes		No	
2.6.4 Have fasteners on the equipment been commonized?		Yes		No	
2.6.5 Has information management been considered in the machine design?		Yes		No	
2.6.6 Are quick release fittings incorporated in high maintenance hydraulic connections and flex drops?		Yes		No	
2.6.6 Are quick release fittings incorporated in high maintenance pneumatic connections and flex drops?		Yes		No	
2.6.6 Are quick release fittings incorporated in high maintenance electrical connections and flex drops?		Yes		No	

Appendix B - Flexible Drops

Flexible Electric Drop



Flexible Air Drop



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